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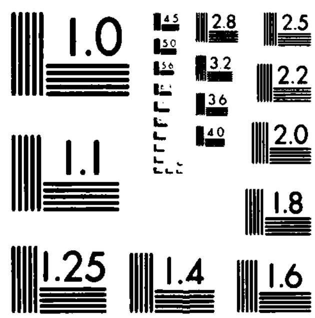

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AFWAL-TR-80-2090

EFFECT OF WATER ON AXIAL FLOW COMPRESSORS

PART I ANALYSIS AND PREDICTIONS

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June 81

TECHNICAL REPORT AFWAL-TR-80-2090, PART I
Final Report for Period 15 December 1977 - 30 September 1980

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This technical report has been reviewed and is approved for publication.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The subject of air-water mixture flow in axial compressors of jet engines is of practical interest in two contexts of water ingestion: during take-off from rough runways with puddles of water and during flight through rain storms. The change in the compressor performance in turn produces changes in the performance of other components and of the engine as a whole. During the current investigation, (i) an analysis of the effects of water ingestion into a compressor has been carried out leading to the development of a predictive code, the PURDU-WICSTK program and (ii) a series of tests have been carried

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out on a small test compressor with mixtures of gases (containing methane gas to simulate steam) and with air-water droplet mixtures. The experimental results have been compared with predictions. It is concluded that the basic effects of water ingestion into compressors arise through (2) blockage, (b) distortion and (c) heat and mass transfer processes, the changes in blade aerodynamic performance being relatively small. In the case of a compressor of small mass flow and pressure ratio and high operating speed, increased quantities of water ingestion give rise to large quantities of water in the tip region. When the pressure ratio and air mass flow are large and the operating speed is correspondingly small, there arises a possibility of water evaporation, especially towards the hub, which gives rise to changes in gas phase mass flow and temperature. The changes in compressor performance are large at high speeds and high flow rates; there also arises a change in the surge characteristics. In light of the nature of changes produced by water ingestion, a preliminary analysis has been carried out on the possible changes in engine performance.

FOREWARD

This final report presents the results of research undertaken at Purdue University under Air Force Contract No. F33615-78-C-2401. The effort was sponsored by the Air Force Aero Propulsion Laboratory, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, under Project 3066, Task 306604 and Work Unit 30660454, with Mr. Larry E. Crawford, AFAPL/TBC, as Project Engineer.

Two earlier publications of direct relevance to the project are as follows:

i) "Water Ingestion into Axial Flow Compressor", Report No. AFAPL-TR-76-77, August, 1976; and

ii) "Analysis of Water Ingestion Effects in Axial Flow Compressors", Report No. AFAPL-TR-78-35, June, 1978.

The research reported in the current report pertains to a further development of a prediction code for the performance of an axial compressor with water ingestion, experimental studies on a small engine-driven axial compressor with water ingestion and an analysis of the results.

The final report consists of three parts, Part I entitled Analysis and Predictions, Part II entitled Computational Program and Part III entitled Experimental Results and Discussion. Each part is presented in a separate volume.

Dr. Bruce A. Reese, currently Chief Scientist at the Arnold Engineering Development Center, Arnold Air Force Base, who was Professor and Head, School of Aeronautics and Astronautics, Purdue University, up to June 30, 1979, participated in the conduct of research from January, 1978 until June 30, 1979.

The Drive Engine and the Test Compressor provided by the Air Force for the experimental studies under this project were manufactured by the Detroit Diesel Allison of Indianapolis. They refurbished the units during this program under a subcontract. In that work and in a variety of ways the DDA and several of their personnel have been most helpful and have given their time and advice generously to the investigators.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF TABLES

<u>NOMENCLATURE</u>

A	compressor flow area
A_p	droplet project area
a	acoustic speed
C_D	drag coefficient
C_{D_f}	drag coefficient corresponding to loss due to water film formed on blade surface
C_{D_r}	drag coefficient corresponding to loss due to rough film surface of water on blade surface
C_w	water vapor concentration
C_{wb}	water vapor concentration at droplet surface
c	blade chord length
c_p	specific heat at constant pressure
c_w	specific heat of water
c_s	humid heat for air-water mixture
D	droplet diameter
D_d	droplet diameter

D_v diffusivity

D_{eq} equivalent diffusion ratio

D_{eq}^* equivalent diffusion ratio at minimum loss point

d_{max} largest stable droplet diameter

g_c Newton constant relating force and mass

h_h heat transfer coefficient

h_m mass transfer coefficient

i incidence angle

i* incidence angle at minimum loss point

J constant relating heat and work

K_a thermal conductivity of air

K_d thermal conductivity of gaseous film surrounding an evaporating droplet

K_v thermal conductivity of water vapor

k thermal conductivity

k_g thermal conductivity of gaseous phase

M absolute Mach number

M_a assumed value of Mach number

M_r relative Mach number

M_c calculated value of Mach number

$\dot{m}$ mass flow rate

$\dot{m}_{film}$ mass flow rate of water film formed on blade surface

mw molecular weight

N rotor rotational speed

N_d number of droplet

Nu Nusselt number

P_{01} total pressure at rotor inlet

P_{02} total pressure at rotor outlet

P_{03} total pressure at stator outlet

$P_{01,r}$ relative total pressure at rotor inlet

$P_{02,r}$ relative total pressure at rotor outlet

$P_{02,ri}$ ideal relative total pressure at rotor outlet

PR pressure ratio

Pr Prandtl number

p_{ref} reference pressure

p_1 static pressure at rotor inlet

p_2 static pressure at rotor outlet

p_3 static pressure at stator outlet

R gas constant

Re Reynolds number

r rudius

s pitch

Sc Schmidt number

Sh Sherwood number

SN stability number

T static temperature

T_o total temperature

T_{ref} reference temperature

$T_{o1,r}$ relative total temperature at rotor inlet

$T_{02,r}$ relative total temperature at rotor outlet

TR temperature ratio

U_{tip} blade tip speed

U blade speed

V_z axial velocity

V absolute velocity

V_θ tangential component of absolute velocity

V_{film} velocity of film formed on blade surface

W relative velocity

W_θ tangential component of relative velocity

We Weber number

x_g mass fraction of gas phase

x_w mass fraction of liquid phase

Greek Letters

α absolute flow angle

β relative flow angle

γ specific heat ratio

η adiabatic efficiency

ΔH_v latent heat of vaporization

ΔH_0 rise in total enthalpy

$(\Delta H_0)_1$ work input to gaseous phase

$(\Delta H_0)_2$ work input absorbed by water droplets which do not impinge upon blade surface

$(\Delta H_0)_3$ work input absorbed by water droplets which impinge upon blade surface, adhere to form a film and are re-entrained from the trailing edge

$(\Delta H_0)_4$ work input absorbed by droplets which impinge upon blade surface and rebound

ΔT_0 rise in total temperature

ΔT_g rise in overall temperature of gaseous phase

$(\Delta T_g)_{ht}$ drop in temperature of gaseous phase due to heat transfer

$(\Delta T_g)_{wk}$ rise in temperature of gaseous phase due to work done

ΔT_w rise in overall temperature of droplet

$(\Delta T_w)_{ht}$ rise in temperature of droplet due to heat transfer

$(\Delta T_w)_{wk}$ rise in temperature of droplet due to work done

δ deviation angle

δ boundary layer displacement thickness

δ corrected pressure ($\delta = p/p_{ref}$)

θ boundary layer momentum thickness

θ corrected temperature ($\theta = T/T_{ref}$)

μ viscosity

ρ density

σ	surface tension of droplet
σ	solidity
σ_v	particulate liquid volume fraction
τ	equivalent temperature ratio
ϕ	flow coefficient
ψ	equivalent pressure ratio
ω	rotor angular velocity
$\bar{\omega}$	total pressure loss coefficient
$\bar{\omega}_{g,R}$	total pressure loss coefficient across rotor due to gas phase
$\bar{\omega}_{g,S}$	total pressure loss coefficient across stator due to gas phase
$\bar{\omega}_{\theta,R}$	total pressure loss coefficient due to the increase of momentum thickness because of the existence of small droplets in the boundary layer over a rotor blade surface
$\bar{\omega}_{\theta,S}$	total pressure loss coefficient due to the increase of momentum thickness because of the existence of small droplets in the boundary layer over a stator blade surface
$\bar{\omega}_{f,R}$	total pressure loss coefficient due to the momentum gained by thick water film moving over a rotor blade surface
$\bar{\omega}_{f,S}$	total pressure loss coefficient due to the momentum gained by thick water film moving over a stator blade surface
$\bar{\omega}_{r,R}$	total pressure loss coefficient due to turbulent flow of mixture over the rough film surface of rotor blade

$\bar{\omega}_{r,S}$ total pressure loss coefficient due to turbulent flow of mixture over the rough film surface of stator blade

$\bar{\omega}_{s,R}$ total pressure loss coefficient due to the Stokesian drag of droplets in rotor passage

$\bar{\omega}_{s,S}$ total pressure loss coefficient due to the Stokesian drag of droplets in stator passage

Subscript

a pertaining to assumed value

c pertaining to calculated value

D pertaining to design point

g pertaining to gas phase

i pertaining to ideal process

l pertaining to liquid phase

m pertaining to mixture

r pertaining to relative value with respect to rotor

ref pertaining to reference value

R pertaining to rotor

S pertaining to stator

w	pertaining to water droplet
0	pertaining to stagnation value
1	pertaining to rotor inlet
2	pertaining to rotor outlet
3	pertaining to stator outlet

<u>Superscript</u>

*	pertaining to minimum loss point
-	pertaining to average value

SUMMARY

The PURDU-WICSTK program developed for predicting the performance of an axial flow compressor operating with mixtures of gases and water droplets has been described in detail. The utilization of the program has been illustrated with a test case.

CHAPTER I

INTRODUCTION

Water ingestion into an aircraft gas turbine arises due to two circumstantial reasons:

(1) wheel-generated spray clouds entering the engine inlet during take-off and landing from a rough runway with puddles of water; and

(2) rain, occasionally mixed with hail, entering the engine inlet during various parts of a flight in a rain storm.

A number of studies (Refs. 1-6) have shown that adverse effects can arise in engine performance due to such ingestion of water at engine inlet, when the engine has been designed for operation with air flow. In particular the engine may surge and may suffer blow-out or unsteadiness in the main burner or the after-burner. Simple corrective steps, such as resetting the throttle, have generally been ineffective in overcoming the problems of loss of power and nonsteady behaviour of the engine. In the case of wheel-spray ingestion, it has again become clear that basic changes in engine installation may be necessary in relation to inlets and landing wheels.

In the current investigation, there is no particular emphasis on the precise cause for the presence of water at the engine inlet. Water is assumed to enter the compressor along with air in droplet form. The droplet (nominal) diameters may be in the range of 20 to 1,300 microns. The water content by weight may be in the range of 2.5 to 15.0 per cent. In case of rain through which an aircraft may have to fly (Refs. 7-9) the droplet sizes may be of the order of 100 to 1,500 microns, although 3,000 micron size droplets have also been reported (Fig. 1.1). On the

other hand, 15.0 per cent of water by weight is probably to be considered as a large amount of ingestion into the inlet, corresponding to flight through storm conditions. Under such extreme conditions there may also be hail and snow ingestion into the engine. However, only water ingestion effects are examined here.

A comprehensive investigation of the problem of water ingestion into engines during flight should take into account details of the engine, its installation and the engine and aircraft controls. In the current investigation attention is focussed on the engine and its control.

Furthermore, it is felt that the response of the compressor in the engine to water ingestion plays a determining and crucial role in the response of the engine as a whole in view of two considerations.

(1) The compressor receives the ingested water directly and, as a rotating machine, is most strongly affected by the ingested water, and also changes the "state of water" before the fluid enters the burner.

(2) The compressor performance most directly affects the operating point of the engine under steady and transient state conditions.*

However, the compressor performance is affected by the presence of an inlet through the changes in the flow field introduced by it, especially the distortion of the compressor inlet flow field. While noting such strong interaction between the inlet and the compressor flow fields, the

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* It may be pointed out that the operating point of an engine is determined by the matching between all of the components of the engine. Thus, the swallowing capacity of the turbine and nozzle, for example in a simple jet engine, at a given engine speed and turbine entry temperature, determine the engine operating point on the compressor map. However, any changes in the compressor outlet conditions affect the engine operating point most directly with a given turbine and nozzle. In particular, during water ingestion, the compressor map becomes completely changed, causing at least a change in the surge margin for a possible operating point and, in extreme cases, a total mismatch between the components. Even with a turbine and nozzle that have variable-area capability, it may become necessary to regulate the compressor outlet conditions independently.

most important aspect of the problem of water ingestion into an engine is still considered to be that pertaining to changes in the compressor performance itself.

In the case of turbofan engines, the air-water mixture upon entering the inlet becomes divided between the fan and the compressor. In particular cases, the compressor stream may have a different water content and droplet size distribution from that of the compressor stream in the absence of a fan. The effects of water ingestion are important both in the fan and the core engine compressor, although, perhaps, more so in the latter. When there is an after-burner in the fan stream or when a "mixing" Nozzle is employed, water ingestion into the fan stream may, however, become critically important.

From practical operational and design points of view, the effects of water ingestion in a compressor are as follows:

(1) changes in temperature ratio, pressure ratio and efficiency of the compressor;
(2) changes in surge line and operating line, and therefore the surge margin under given operating conditions;
(3) blade deformation and erosion due to impact of droplets;
(4) blade and casing deformation due to differential thermal expansion under transient conditions;
(5) oscillation of pressure ratio and flow; and
(6) changes in dynamic loading including aero-elastic effects.

For given entry conditions, the response of the compressor is determined by the following:

(1) compressor geometry;
(2) blade loading;
(3) machine rotational speed; and
(4) parameters of the engine of which the compressor is a part.

The latter pertain to engine matching and should include not only the steady state performance parameters but also the mechanical, aerodynamic and thermal inertia of the various components of the engine

under transient conditions. It should be noted that in particular cases, the engine components may include a fan, an after-burner or a second nozzle as part of the engine.

In establishing the response of a compressor to water ingestion, it seems therefore useful to divide the total problem into two parts.

(1) The compressor as a machine itself; and

(2) The compressor as a part of the engine system.

In that fashion, one can separate the problems associated with engine matching (steady or transient) from those dependent upon the design of the compressor itself. Once the latter have been understood in detail, the engine as a whole may be studied from a system point of view. This is the approach adopted in the current investigation, since it is also especially convenient in conducting experimental studies.

A number of parameters pertaining to the air-water mixture entering a compressor during water ingestion are the following:

(1) amount of water approaching and actually entering a blade row as a fraction of the total mass flow of fluid entering compressor;

(2) form in which water is present, film and droplets;

(3) temperature and pressure of air, temperature of water and temperature of machine;

(4) vapor content;

(5) turbulence; and

(6) distortion, radial and circumferential.

Water vapor is always present in air-water mixtures ingested into an engine. The water vapor content changes in the compressor because of changes in pressure and temperature and because of transfer processes between the two phases. In particular, in a multi-stage compressor of large pressure ratio, there is a possibility of some of the water reaching local saturation temperature and undergoing a phase change due to boiling causing addition of large quantities of vapor to the gas phase.

It will be observed that each of the afore-mentioned six parameters changes after each blade row and the cumulative changes are therefore especially significant in a multi-stage machine. Furthermore, both time-dependent changes during sudden and sporadic ingestion, as well as steady state changes, as, for example, may arise in a laboratory experiment, need consideration. Thus, a detailed study of this problem should result in the determination and verification of methods for establishing (a) the changes in the performance of a compressor with water ingestion and (b) the changes in the state of fluid between the inlet and the outlet of the compressor. Such a study requires investigations both on a single row of blades (stationary and rotating) as well as on a unit with several rows of blades, under steady, transient, and distorted flow conditions. The latter is a means of establishing the response of a blade row to the flow generated by a preceding row. Furthermore, in order to examine the occurrence and effects of phase change in a blade row, the entry conditions to the blade row have to be selected such that they are suitable for such phase change. In a multi-stage compressor of large pressure ratio, there is, of course, a considerable change in air temperature at design conditions.

However, at this stage there are still considerable problems in conducting detailed measurements of two-phase flows in rotating machinery. It has therefore been felt in this investigation that one should aim at establishing overall performance changes and fluid flow changes in a compressor for given entry conditions of state of the two-phase fluid. Once such overall changes are established and related to verifiable models for performance prediction, it is felt one can proceed to more detailed measurements and modeling.

For a given compressor, the variables of interest during water ingestion are the following:

(1) speed of the machine;
(2) throttle setting;
(3) stagnation pressure
(4) temperature of air and water;

(5) amount of water as a fraction of total mixture flow;

(6) droplet size and number density distribution, and

(7) vapor content.

The variables (3) to (7) have a spanwise and circumferential distribution at compressor inlet, which may or may not be uniform.

The overall performance parameters of a compressor with two-phase flow are the following:

(1) pressure ratio temperature ratio and efficiency;

(2) changes in total water content and droplet size across the compressor; and

(3) changes in vapor content across the compressor.

Each of these varies along the span of a compressor blade. Both the measurements and prediction of these is beset with considerable difficulties at this time. In particular the determination of water and vapor content and of droplet size distribution requires further advances in instrumentation, data acquisition and data processing.

On establishing and demonstrating predictive methods for the estimation of such overall performance parameters for a compressor, an analysis can be carried out for an engine operating with water ingestion. Under steady conditions, the equilibrium running of a simple engine depends upon the following parameters:

(1) engine speed;

(2) mass flow;

(3) compressor performance with air-water mixture;

(4) ratio of turbine entry temperature to inlet temperature;

(5) turbine operational point (choked or unchoked); and

(6) thrust nozzle geometry.

Regarding the latter, a fixed geometry thrust nozzle with a constant area turbine restricts the number of variables for equilibrium running of a simple engine to a single parameter, namely engine speed or mass flow. In a variable geometry engine which permits changes in area of the turbine and the thrust nozzle, one can select, at least in principle, three variables independently for equilibrium running; engine speed, mass flow and turbine entry temperature.

An analysis of steady state equilibrium running of an engine with water ingestion can be expected to reveal the following:

(1) whether equilibrium running is feasible under a given set of operating conditions,

(2) changes in surge margine, and

(3) effect of fuel scheduling and bleed of working fluid.

The latter, along with other aspects of engine operation, is dependent upon the type of engine control incorporated in the system.

Even when attention is focussed on the performance of a compressor by itself, several aspects of the performance may come to light only when it is operated as a part of an engine. However, if engine matching and its effect on compressor performance are not included, one can test a compressor as a separate unit by driving it, for example, with an aerodynamically-independent drive engine. This has been the basis for experimental studies in the current investigation.

1.1 Objectives and Scope of the Investigation

The principal objectives of the present investigation are as follows:

(1) Establishment and demonstration of a predictive method for the calculation of the performance of an isolated compressor driven by an external drive unit and operating with air-water mixture flow; and

(2) Obtaining and correlating experimental data on a multistage compressor with air-water mixture flow.

In both of the above, the vapor content of the mixture is taken into account, both initial humidity and changes in vapor content due to phase change of water droplets.

The other objectives of the present investigation are as follows:

(1) Determination of the manner in which engine performance becomes affected by water droplet ingestion into the engine compressors; and

(2) Providing a review of instrumentation suitable in compressor.

1.1.1 Analytical-Predictive Investigations

The analytical-predictive investigations are divided into two parts; (1) investigation on the performance of a compressor with water ingestion, and (2) analysis of a simple gas turbine engine with water ingestion.

Part I: Performance of Compressor with Water Ingestion

The analytical-predictive investigations on performance of compressor with water ingestion are divided into three parts:

(1) Setting up the general aero-thermodynamic equations for compressor with air-water mixture flow and deduction of a one-dimensional model.

(2) Establishing one-dimensional models for the estimation of performance of a compressor in four limiting cases as follows:

   (i) Ingestion of mixtures of gases directly into a compressor at inlet, without water droplets.

   (ii) Ingestion of small droplets that can be assumed to follow gas motion and hence absorb angular momentum.

   (iii) Ingestion of large droplets that can be assumed to move with equal probability in all directions and that cause a loss of compressor performance due to drag forces acting on them; and

   (iv) Injection of water with sudden phase change into steam at an appropriate stage in the compressor.

(3) Adapting and exercising a three-dimensional streamline computer code, the UD-0300 computer code (Ref.10), for the case of direct ingestion of mixtures of gases into a compressor.

Part II: Analysis of Gas Turbine Engine with Water Ingestion

The objectives of Part II are as follows:

(1) Establishing a model for steady state engine matching with water ingestion; and

(2) Establishing a model for calculation of flight performance with water ingestion.

1.1.2. Experimental Investigation

The experimental investigations have been conducted on a specially built Test Compressor. The experimental investigations may be divided into the following three parts:

(1) Tests with air as the working fluid;

(2) Tests with air-methane mixture as the working fluid; and

(3) Tests with air-water droplet mixture as the working fluid.

The Air Force System Command has provided the Test Compressor and a T-63 Drive Engine for the experimental investigations. The predictive methods developed for estimating compressor performance with two phase flow have also been employed to calculate the performance of the Test Compressor.

Details regarding the Test Compressor and Drive Engine are provided in Appendix 1 to this Report.

The Test Compressor, it will be observed, has several limitations:

(1) the annulus and the blade heights are small and only overall performance parameters at one or at most two radial locations at the exit plane can be measured.

(2) the overall pressure and temperature ratios, even at design point, are too small to cause evaporation of more than 2.5 per cent of water (by weight) although the inlet temperature is raised to as high a value as 185°F (85°C).

(3) the compressor assembly permits little flexibility in locating instrumentation, especially at the compressor exit.

Since the Test Compressor casing has a plastic coating that does not

withstand high temperatures, the Test Compressor has been tested at low inlet temperatures in the range of 70^{o}F to 100^{o}F (about 20^{o}C to 40^{o}C). Such inlet temperatures do not cause water evaporation within the Test Compressor. The test program has therefore been conducted in two parts:

(1) With a mixture of gases to simulate air-steam mixture flow corresponding to (a) high humidity in the air and (b) operation of different stages with air-steam mixture following complete evaporation of water, and

(2) With air-water droplet mixture flow.

In examining the effects of presence of water vapor on a compressor performance, it is clear that another gas, such as methane, can be substituted for water vapor so long as the desired similarity laws with respect to Reynolds and Mach numbers, are satisfied. A comparison of properties for steam and methane is presented in Table 1.1. In view of the similar properties, experimental studies have been undertaken in this investigation utilizing air-methane mixtures.

The tests with air-water droplet mixtures have been conducted utilizing the following variables: mixture temperature, mixture composition and droplet size.

1.1.3 Measurements and Predictions

The results of the experimental investigation have been compared with prediction from models from the point of view of examining selected assumptions introduced in the models. It is clear that in view of limitations on the feasibility of measurements and the nature of assumptions introduced in modeling, comparison of analytical predictions with experimental results is restricted to certain overall performance parameters, in particular, the effects of mechanical-aero-thermodynamic interactions are established indirectly from overall compressor performance parameters and changes in water and vapor content.

TABLE 1.1

COMPARISON OF PROPERTIES FOR STEAM AND METHANE

	Steam	Methane
Chemical Formula	H_2O	CH_4
Molecular Weight	18.016	16.043
Specific Heat at Constant Pressure		
(Btu/lbm-^{o}F)	0.445**	0.531*
(kJ/kg-^{o}C)	1.863**	2.223*
Ratio of Specific Heats*	1.329**	1.304*
Enthalpy Increase		
(Btu/lbm)	62.70^{+}	69.96^{+}
(kJ/kg)	145.84^{+}	162.73^{+}

*pressure = 1 atm; temperature = 78^{o}F(26^{o}C)

**pressure = 1 atm; temperature = 212^{o}F (100^{o}C)

$^{+}$ pressure ratio, P_{02}/P_{01} = 2.6; T_{01} = 68^{o}F (20^{o}C)

1.1.4 Measurement Techniques

A brief review of instrumentation suitable for use in axial flow compressors and cascades operating with two phase fluid flow has been undertaken.

Two important overall performance parameters in compressors are the stagnation pressure ratio and the stagnation temperature ratio. A probe for the measurement of stagnation pressure in two phase flow has been developed. Its possible use in a compressor flow field has been examined. The development of a similar probe for the measurement of stagnation temperatures has been considered.

1.1.5 Engine Performance

The engines considered are those that have been designed for air flow through the inlet. Engines in which there may be injection of water at gas flow part locations beyond the compressor or in other stream such as fan ducts or after-burners are not under consideration. Specifically water ingestion effects have been examined in the case of simple turbo-jet and turbo-fan engines that have originally been designed for air flow operation only. Thus (a) the adverse flow effects due to water ingestion and (b) possible methods of mitigating such effects are of interest.

The response of an engine to water ingestion depends upon the following:

(a) component geometrical constraints;
(b) component performance characteristics; and
(c) nature of control incorporated into the engine.

The performance characteristics that are of major interest are the following:

(a) Changes in component performance characteristics due to water injection, in particular the compressor;
(b) Changes in operating characteristics of engine under conditions of equilibrium running;

(c) Changes in surge margin; and

(d) Limiting conditions of operation.

The foregoing have been analyzed in order to establish general performance trends without reference to specific engine configurations.

It may be noted that, because of the aero-thermo-mechanical processes arising on account of water ingestion, one may also expect, at least in extreme cases, aero-elastic processes becoming significant. However, the manner in which flutter, for example may be altered during two phase flow in compressors is not included for study in the current investigation.

1.2 Effects of Water Ingestion

The two critical factors during water ingestion may be said to be the following: (a) the aero-thermo-mechanical processes associated with two phase flow and (b) the centrifugal action on droplets in the compressor. The first of these includes droplet disintegration and evaporation processes. The latter gives rise to a change in gas phase mass flow as well as reduction in gas phase temperature. The centrifugal action introduces a radial distortion in the flow and fluid properties, and the distortion changes in every stage of a multistage compressor. In particular, the spanwise distribution of the composition and properties of the fluid, in terms of air, water vapor and water droplets (both content and size distribution), undergoes changes continuously along the compressor flow path. The effects (a) and (b) should be examined in a compressor in relation to the following:

(i) Formation of a water film in the tip region, that may flow into the diffuser;

(ii) Possibility of choking hub sections and stalling tip sections with redistributed gas and liquid phase mass flow; and

(iii) Nonuniform distribution of water vapor in the radial direction.

The foregoing will in turn affect engine performance depending

upon engine-matching and the type of control in the engine.

In order to reduce the effects of water ingestion, one can consider the following in order of increasing complexity.

(i) Bleeding of gas or liquid phase flow at appropriate locations in the compressor;

(ii) Resetting stator blades;

(iii) Modifying engine control; and

(iv) Introduction of variable geometry nozzle and also turbine.

The results of some preliminary studies on bleeding and also gas injection have been reported in Ref. 11.

1.2.1. Relation to Other Two-Phase Flow Problems in Turbo-Machinery

The current investigation deals with air-water droplet mixture ingestion into engines. On the other hand there has also been considerable interest in the problem of dust particle ingestion into engines (Refs. 12-13). In the latter case the principal interest is in erosion of blades and nozzles, although there is some loss in aerodynamic performance.

It is generally considered that the solid particulates may agglomerate but not disintegrate during dust ingestion. Furthermore the heat and mass transfer processes between the two phases are considered negligible.

Solid particulates are also of interest in certain rocket motor nozzle and plume flows (Refs. 14-16). In this case, in addition to erosion and particulate drag effects it is generally necessary to take into account heat and mass transfer processes, as well as condensation, solidification and other phase change processes. However, in this case there is not strong centrifugal action, although there may be some swirl in the flow.

The low pressure stages of a steam turbine (Refs. 17-19) may

operate, as is well known, with steam-water droplet mixture, the droplets arising through condensation. However, in this case, while erosion, loss of aerodynamic performance, and consequences of strong centrifugal action are important, one does not have the problems of stalling and surging. A compressor is prone to surging and the surge margin with respect to operating line when it is part of an engine is an extremely important parameter in engine operation. Hence the problem of water ingestion into an engine compressor attains a leval of complexity and significance much larger than the two phase flow problem in steam turbines. One should also note that a turbine is basically a nozzle, while a compressor flow (both past a blade and through a blade passage) involves diffusion and complicated blade wake interactions.

The current investigation does not take into account geometrical changes in a compressor because of, say, differential contraction of rotor and casing upon water ingestion. In general one can expect a change in clearance between rotor and stator. If a compressor has been designed with optimum clearance, one has to examine both aerodynamic and mechanical effects caused by changes in clearance. This aspect of water ingestion should be examined in relation to the general problems of gas flow path integrity (Ref. 20).

While nonsteady state operation is not considered in the current investigation, one of the most important aspects of water ingestion into compressors and engines is transient state operation. The aero-thermo-mechanical interactions including differential contraction of casing and rotor under transient conditions are significant in evolving various means of reducing the effects of water ingestion.

Finally, it is recognized that the entry conditions into a compressor are not uniform radially and circumferentially. The effects of distortion with respect to pressure, temperature, velocity and turbulence continue to be a subject of concern even with air flowing alone (Ref. 21). During water ingestion, one can expect, in general, distortion both at entry and to the compressor and at entry to each stage. The sensitivity

of an engine to water ingestion should include consideration of inlet distortion with regard to water content and water droplet size distribution. This problem has been entirely neglected in the current investigation. It may be pointed out that even under uniform inlet flow conditions, radial distortion, of course, arises within the compressor due to centrifuging and heat and mass transfer processes.

1.3 Implications of Models

The models derived in the current investigation may be divided into four groups:

(i) Model for the calculation of stage performance with air flow.

(ii) Model for droplet motion across a blade row.

(iii) Model for centrifuging of water, and

(iv) Model for heat and mass transfer processes, including droplet disintegration.

Experimental investigations have been conducted in order to determine overall compressor performance changes for given initial and operating conditions. A comparison between predictions and measurements therefore yields no detailed verification of the models. It is in any case doubtful if detailed verification of all aspects of the models can be obtained even if one attempted additional measurements.

The performance of a compressor stage with two phase flow depends upon the following parameters:

(i) geometrical design of blade and blade passage,

(ii) spacing between blade rows,

(iii) leading and trailing edge geometry,

(iv) casing geometry,

(v) rotor and stator blade junctions,

(vi) incoming flow conditions, and

(vii) operating speed and throttle setting

The foregoing determine (a) the stage work input, (b) the states

of gas and liquid phases, (c) the efficiency of compressor, (d) the redistribution of water and vapor and (e) limiting condition of steady state operation of compressor. When the compressor is part of an engine, the operating characteristics of all other components of the engine and of the engine as a whole are also determined by the compressor design and initial conditions. It is clear that while the models developed can be employed to determine the performance of any compressor under a set of reasonable operating conditions, there is need to establish relations that can be employed to scale the performance of a compressor with respect to design, initial and operating conditions. Such scaling laws have to be based on characteristic lengths, characteristic times, and blade, blade passage and blade row characteristics of the compressor and, when the compressor is part of an engine, the characteristics of other components such as diffuser, burner, turbine and nozzle. Under certain assumptions an attempt has been made to establish scaling laws for both a compressor and a simple jet engine.

1.4 Organization of Report

The final report is being issued in three parts:

Part I: Analysis and Predictions

Part II: Computational Programs; and

Part III: Experimental Results and Discussion

This report constitutes Part II of the Final Report. Chapter I is the introduction. Chapter II is devoted to a discussion of overall program structure, and Chapter III presents a detailed description of the subroutines and external functions. The description of input data is given in Chapter IV while a description of the output is presented in Chapter V. Finally, a test case is discussed in Chapter VI.

CHAPTER II

OVERALL PROGRAM DESCRIPTION

The numerical-computational work undertaken in the current investigation may be divided into two parts as follows.

(1) Modification of UD-0300 computer program for use with mixtures of gases; and

(2) Development and use of PURDU-WICSTK program for the calculation of performance of axial compressors operating with air-water droplet mixture, based on one-dimensional flow analysis.

The modification of UD-0300 program for use with mixtures of gases is described in detail in Ref. 22. Typical performance results for the Test Compressor employed in this investigation, based on the UD-0300 program, are also presented in Ref. 22.

The PURDU-WICSTK program is described in the following.

2.1 Description of PURDU-WICSTK Program

The one-dimensional flow equations for two phase flow in axial compressors have been derived in detail and presented in Ref. 22. Those equations are suitable for the calculation of performance of any chosen section along the span of an axial compressor blade row. The PURDU-WICSTK is based on those equations. For given initial conditions at the entry to a stage, the outlet conditons can be calculated using those equations.

The PURDU-WICSTK deals with a fluid that may consist of (a) a mixture of three different gases and (b) a mixture of two types of water droplets, distinguished by size. The mixture of gases may consist of air, water vapor or steam, and methane. The water droplets may be "small" and

"large" diameter droplets. Small droplets are defined as those that follow the gas flow path and hence, absorb work input into the compressor along with the gaseous phase. Large droplets are assumed to move largely independently of the gas phase, with equal probability of motion in all directions and without absorbing work input but introducing drag losses. In the general two-phase mixture that is considered as the working fluid in the compressor, the proportion of the five constituents (namely, three gases and two types of droplets) may be chosen as desired in the initial conditions assumed for a calculation. Thus, to consider humid air carrying large droplets, the content of methane and of small droplets are set equal to zero while water vapor content is related to humidity.

The performance of a stage of a compressor is based in the PURDU-WICSTK Code on five physical models as follows.

(1) Model for the calculation of stage performance with respect to the gaseous phase and water droplets.

(2) Model for droplet motion across a blade row from a chosen upstream location to a designated downstream location.

(3) Model for centrifuging of water droplets.

(4) Model for heat and mass transfer processes between the two phases; and

(5) Model for droplet break-up and equilibration with respect to size.

The foregoing five models have been described in detail in Ref.22. However, a further description is included in Appendix 2 of this report regarding the model for the calculation of stage performance with respect to gaseous phase and water droplets.

The general procedure for calculation is the same as described in Ref. 22. The performance of a stage is calculated for given initial and operating conditions with respect to the gaseous phase and the water droplets. Regarding small droplets, any fraction of their total number may be taken into account depending upon assumptions relating to droplet impingement and rebound processes. Details are provided in Ref. 22. Then, at the exit of a blade row, the three major processes, namely

(1) centrifugal action on droplets, (2) heat and mass transfer processes between the two phases and (3) droplet size adjustment, are taken into account. When the stage performance parameters are corrected for the afore-mentioned three processes then one obtains the outlet conditions from a stage.

The outlet conditions from a stage are modified, to account for geometry of compressor, in order to obtain the initial conditions for the next stage, where such exists.

Calculations are repeated for subsequent stages based on the well-known concept of stage-stacking.

The Code can be used to predict the design point performance as well as off-design performance of a multi-stage compressor. Regarding off-design performance calculation, further details are provided in Appendix 2 of this report.

The Code is also suitable for the calculation of compressor performance with (a) bleeding of working fluid at different stages in the compressor and (b) resetting stator blades. It may be recalled that two of the recommended methods for mitigating the effects of water ingestion in compressors consist in (a) bleeding of working fluid and (b) resetting of stator blades.

The program is written for calculation of performance both in British and metric units.

2.2 Main Program

The program consists of a main program, twenty seven subroutines and thirteen external functions.

The main computer code routine is entitled MAIN. It calls all of the major subroutines in the code.

MAIN first reads all of the input data and prints them out. Then MAIN calls the subroutine WICSPD to calculate the design point performance.

At the compressor inlet the overall mixture mass flow rate is determined from the inputed initial overall flow coefficient and selected compressor operating speed. In order to calculate the stage performance, it is necessary to establish the stage axial velocity and stage flow coefficient at the entry to the stage. The axial velocity and therefore the stage flow coefficient are determined by the composition of the mixture. The influence of mixture composition arises through (a) the density of the mixture and (b) the proportion of large droplets in the mixture, the large droplets, it may be recalled, having random motion with respect to the gas phase and the small droplets. Details regarding stage flow coefficient are provided in Ref. 22 and Appendix 2 of this report.

2.2.1 Work Done in Stage

The stage performance calculation may be carried out in one of three ways by setting the input parameter IPERFM equal to 1,2, or 3: (1) WICSPA is called to utilize inputed stage characteristics; (2) WICSPB is called to utilize the analytical/correlation method(Appendix 2) for small droplets; and (3) WICSPC is called to utilize method described in Appendix 2 for large (or general) droplets. The program is written such that if more than 20 per cent of droplets belong to the class of large droplets, WICSPC is always used.

The foregoing stage performance calculation refers only to the determination of work done by the stage on the fluid that is assumed to absorb work input into the stage. The state of the fluid at the exit of the stage is then obtained by accounting for (1) the centrifugal action on droplets leading to a redistribution of liquid phase, (2) heat and mass transfer processes leading to a redetermination of mass flow and temperature of both gas phase and liquid phase.

2.2.2 Droplet Impingement Processes

In order to perform calculations pertaining to impingement of droplets on rotor blades and rebound of droplets, MAIN calls subroutine WICIRS and WICIRL for small and large droplets, respectively. The small and large droplet trajectories are different by assumption and their impingement on blades, therefore, has to be calculated in different ways. For stator blade, the subroutines WICISS and WICISL are called for small and large droplets, respectively.

The rebound of droplets is treated parametrically as a fraction of the droplets that impact a blade. The unrebound droplets are assumed to move over the blade surface and to be reingested into the blade wake at the blade trailing edge. Details regarding these processes may be found in Ref. 22.

2.2.3 Droplet Drag

The stage performance calculation described earlier yields a value of gas phase pressure at the stage exit. This to be corrected for droplet drag in the case of large droplets. The droplet drag due to large droplets is accounted for by calling the subroutine WICDRG. The pressure loss due to drag depends upon (a) the chosen drag coefficient, and (b) the number of droplets taken into consideration. The latter in turn depends upon the droplet impingement and rebound processes. Further details may be found in Ref. 22.

2.2.4 Droplet Size Adjustment

At the trailing edge of a blade, it is necessary to establish (a) the size of droplets that re-entrained into a blade surface and (b) the nominal size of all of the droplets. In both cases, the droplet size is assumed to be determined by the critical value of Weber number. The subroutine WICWAK yields the size of droplets that are re-entrained. Regarding the nominal size of all of the droplets in the blade wake region, the WICSIZ is called to determine it. It may be observed that the droplets attain an equilibrium size in the blade wake region only after traversing a distance since the droplets undergo an accelerating motion starting from the blade trailing edge till they attain momentum equilibrium with respect to the gas phase.

2.2.5 Centrifugal Action

The spanwise redistribution of droplets due to centrifugal action is based on the theory developed in Ref.22. The centrifugal action arises due to (a) the whirl component of velocity of droplets and (b) the rota-

tional motion of blades in a rotor. In the case of small droplets, centrifugal action thus applies to (i) droplets in blade passages with respect to the whirl component of velocity and (ii) droplets on blade surfaces with respect to the blade rotational velocity. In the case of large droplets, on the other hand, centrifugal action arises only for droplets that impact the blade and are not rebound; in other words, for droplets that impinge on a blade and remain on it.

The centrifugal action arises both in a stator and a rotor for small droplets, while it arises only in a rotor for large droplets. This is again based on the earlier postulated difference between small and large droplet motion.

The centrifugal action is determined utilizing the subroutine WICCEN.

It may be pointed out that the spanwise redistribution of droplets due to centrifugal action is a time-dependent process. In other words, the total effect of centrifugal force is proportional to the length of time over which the force acts. It is assumed in the model adopted here that the time over which centrifugal force action arises on a droplet during its passage through a blade row is the mean length of time required for transit through the blade row. Thus, the particles at the trailing edge of a blade row, as they come out of a blade row, are assumed to be centrifuged at that location over a period of time equal to the time of passage through the blade row under consideration. A similar assumption applies if a complete stage is being considered. Further detalis are available in Ref. 22.

2.2.6. Heat and Mass Transfer Processes

The heat and mass transfer processes between the two phases are also time-dependent processes. The mean duration of time for heat and mass transfer processes across a blade row or a stage is again calculated on the basis of mean transit time through a blade row or a stage. The heat transfer is from the gas phase to the liquid phase. The mass transfer arises due to two reasons as follows.

(i) The change of pressure and temperature in a stage and the resulting change in thermodynamic equilibrium conditions and,

(ii) the evaporation of water when conditions are appropriate.

The details of models for heat and mass transfer calculations are presented in Ref. 22.

The heat and mass transfer calculations are carried out by calling the subroutines WICHET and WICMAS, respectively, at the exit of a stage.

The stage exit conditions are thus fully established and are printed out.

2.2.7. Multi-Stage Compressor Performance

When there is a stage following the stage for which exit conditions have been determined, the inlet conditions to the following stage are determined taking into account changes in the geometry of the interstage spacing. Utilizing those conditions as the input conditions, the performance of the following stage is established in terms of final exit conditions from that stage. The procedure is the same as that described for the first stage.

This procedure is continued for all of the stages in the case of a multi-stage compressor and the exit conditions from the last stage are printed out as the output conditions of the compressor for given initial conditions into the first stage of the compressor at the chosen operating speed.

2.3 Off-Design Performance

In order to calculate the performance of a stage at an off-design point, with respect to speed and/or mass flow, one utilizes the subroutine WICSPA, WICSPB, or WICSPC by setting the input parameter IPERFM = 1, 2, or 3. The utilization of the three subroutines is the same as at the design point.

It may be pointed out that the profile loss calculation procedure set out in the subroutine WICGSL is considered especially suitable for the case of the Test Compressor employed in the current investigation. In another case, appropriate modifications or even a replacement of this procedure may become necessary.

2.3.1. Corrections at Stage Exit

In Section 2.2, the methods of applying corrections to the basic stage performance with respect to the following have been discussed.

(1) droplet impingement processes,

(2) droplet drag loss,

(3) droplet size adjustment,

(4) centrifugal action, and

(5) heat and mass transfer process.

It may be recalled that the corrections are related to (a) the assumed distinctions between small and large droplets, and (b) the parametrization of droplet impingement, rebound and reingestion.

In performing off-design performance calculations, the procedure is the same as described in Section 2.2. The distinctions between small and large droplets remain the same. One can, of course, introduce desired values for droplet impingement, rebound and reingestion at each calculation point.

2.4 Bleeding and Injection

At the exit of any stage of a compressor, the output yields the composition of the mixture of gases and liquid droplets. In establishing inlet conditions into the following stage, in addition to taking into account changes due to the geometry of inter-stage spacing, one can take into account bleeding or injection of any component of the mixture by adjusting the mass flow and the mixture ratios.

2.5 Stator Blade Setting

The program includes a provision for blade setting as feature of off-design performance calculations. Further details are provided in Appendix 2.

2.6 Calculation of Stage Losses

The calculation of stage losses is fully described in Appendix 2. A summary is provided here.

The stage loss calculation consists of the following five subroutines:

(1) Subroutine WICGSL
single-phase (gas) flow profile loss calculated using the analytical/correlation method;

(2) Subroutine WICSDL
loss for small droplets on account of the change in momentum thickness of boundary layer due to the presence of such droplets;

(3) Subroutine WICSTL
loss due to Stokesian drag of droplets in the free stream of blade passage;

(4) Subroutine WICFML
loss due to film formed on blades when large droplets are present either by themselves or along with small droplets; and

(5) Subroutine WICRSL
loss due to the mixture boundary layer formed over the rough film surface referred to in (4).

The calculation schemes for various types of working fluids are as follows.

(a) In dealing with the flow of gas phase along, two options exist as follows.

(1) Using inputed stage characteristics by utilizing subroutine WICSPA; or

(2) Using analytical/correlation method by utilizing the relevant part of subroutine WICSPB and WICGSL.

(b) In dealing with the flow of a mixture of gas and small droplets, again two options exist as follows.

(1) Using inputed stage characteristics through the use of WICSPA and correct for the pressure of droplets by using the subroutine WICSDL; or

(2) Using analytical/computational method according to subroutines WICSPB, WICGSL, and WICSDL.

(c) Finally, in dealing with the flow of a mixture of gas and large or large and small droplets, one proceeds by using the subroutines WICSPC, WICGSL, WICSTL, WICFML, and WICRSL.

2.7 Overall Program Structure

The overall program structure is presented in Fig. 2.1 and also described below step by step.

Step 1: Read input data.

Step 2: Printout inputed data.

Step 3: Calculate the design point performance by calling WICSPD.

Step 4: Read initial flow coefficient.

Step 5: Calculate mass flow rate of gas phase and liquid phase from the inputed initial flow coefficient. The subroutine WICPRP and WICMAS are called.

Step 6: Calculate stage performance in one of the following five cases:

(i) If there is no liquid phase, and the inputed stage characteristic curves are to be used, WICSPA is called.

(ii) If there is no liquid phase, and analytical/correlation method is to be used, WICSPB is called.

(iii) If more than 80 per cent of droplets belongs to "small" droplet, and the inputed stage characteristic curves are to be used, WICSPA is called.

(iv) If more than 80 per cent of droplets belongs to "small" droplet and the analytical/correlation method is to be used, WICSPB is called.

(v) If more than 20 per cent of droplet belongs to "large" droplet, WICSPC is called.

Step 7: Calculation of droplet impingement on rotor blade:
For small droplets, WICIRS is called.
For large droplets, WICIRL is called.

Step 8: Droplet size adjustment at rotor outlet: WICWAK and WICSIZ are called.

Step 9: Calculation of centrifugal action and spanwise redistribution of droplets:
For small droplet,WICCEN and WICDMS are called.
For large droplet, WICCEN and WICDML are called.

Step 10: Calculation of droplet impingement on stator blade:
For small droplet, WICISS is called.
For large droplet, WICISL is called.

Step 11: Droplet size adjustment at stator outlet: WICWAK AND WICSIZ are called.

Step 12: Calculation of heat transfer:
WICHET is called.

Step 13: Calculation of mass transfer:
WICMAS is called.

Step 14: Printout stage performance.

Step 15: Repeat steps (6) ∿ (14) until the complete stage performance is obtained.

Step 16: Calculate the overall performance and print them out.

Step 17: Repeat steps (4) ∿ (16) for a new value of initial flow coefficient.

CHAPTER III

SUBROUTINES AND EXTERNAL FUNCTIONS

There are 27 subroutines and 13 external functions in this program. The following is the list of subroutines and external functions. Only brief descriptions of these subprograms are given here. A more detailed description of each subprogram is presented in Appendix 3.

Subroutine WICSPA: calculation of stage performance based on the imputed stage characteristic curves.

Subroutine WICSPB: calculation of stage performance based on the analytical/correlation method for small droplet.

Subroutine WICSPC: calculation of stage performance based on the analytical/correlation method for large droplet.

Subroutine WICSPD: calculation of design point performance.

Subroutine WICSCC: calculation of the equivalent pressure ratio, equivalent pressure ratio, equivalent temperature rise ratio, and stage adiabatic efficiency for a particular stage based on the imputed stage characteristic curves.

Subroutine WICGSL: calculation of single-phase (gas) flow loss.

Subroutine WICSDL: calculation of loss for small droplets on account of the change in momentum thickness of boundary layer due to the presence of such droplets.

Subroutine WICSTL: calculation of loss due to Stokesian drag of droplets in the free stream of blade passage.

Subroutine WICFML: calculation of loss due to film formed on blade surface when large droplets are present either by themselves or along with small droplets.

Subroutine WICRSL: calculation of loss due to the rough surface when large droplets are present either by themselves or along with

Subroutine WICVT: calculation of components of velocity triangle and angles.

Subroutine WICCEN: calculation of swanwise replacement of droplets due to centrifugal action.

Subroutine WICDMS: calculation of amount of small droplets which is centrifuged.

Subroutine WICDML: calculation of amount of large droplets which is centrifuged.

Subroutine WICDRG: calculation of drag force on droplet.

Subroutine WICMAC: calculation of Mach number.

Function WICASD: calculation of acoustics speed in two phase flow.

Subroutine WICBOA: calculation of blade outlet angle.

Subroutine WICEDD: calculation of equivalent diffusion at design point.

Function WICED: calculation of equivalent diffusion.

Function WICMTK: calculation of dimensionless momentum thickness.

Function WICLOS: calculation of total pressure loss coefficient.

Subroutine WICIRS: calculation of droplet impingement and rebound in rotor for small droplet.

Subroutine WICIRL: calculation of droplet impingement and rebound in rotor for large droplet.

Subroutine WICISS: calculation of droplet impingement and rebound in stator for small droplet.

Subroutine WICISL: calculation of droplet impingement and rebound in stator for large droplet.

Subroutine WICWAK: Calculation of water reingestion into wake.

Subroutine WICHET: calculation of heat transfer between gaseous phase and droplets.

Subroutine WICMAS: calculation of mass transfer between gaseous phase and droplets.

Function WICMTR: calculation of mass transfer rate.

Function WICPWB: calculation of vapor pressure.

Function WICNEW: calculation of new trial value in the iterative procedure.

Function WICTAN: calculation of the value of tangent function.

Function WICBPT: calculation of boiling point.

Function WICSH: calculation of specific humidity.

Subroutine WICSIZ: calculation of nominal droplet size.

Subroutine WICPRP: calculation of flow properties for gaseous phase.

Function WICCPA: calculation of specific heat at constant pressure for air.

Function WICCPH: calculation of specific heat at constant pressure for vapor.

Function WICCPC: calculation of specific heat at constant pressure for methane.

CHAPTER IV

INPUT DATA

All input data that are needed to use PURDU-WICSTK computer code are decribed in this section. The input data are presented in the same sequence as they are used in the program. The units for the input data can be selected as either all Metric or all English by choosing the value of IUNIT as shown in Table 4.1.

The following is a list of the input data as they are read in MAIN. Figures 4.1 and 4.2 show the geometry of compressor stage and angles associated with a typical rotor blade element.

Card No.	Input Data	Comment	Format
1	NS	number of stage	I1
2	RRHUB(I)	hub radius at Ith stage rotor inlet. $I = 1 \sim NS$ Unit: inch or cm	F5.3
3	RC(I)	chord length of Ith stage rotor $I = 1 \sim NS$ Unit: inch or cm	F 5.3
4	RBLADE(I)	number of blade for Ith stage rotor. $I = 1 \sim NS$	F 5.2
5	STAGER(I)	stager angle for Ith stage rotor $I = 1 \sim NS$ Unit: degree	F 5.2
6	SRHUB(I)	hub radius at Ith stage stator inlet. $I = 1 \sim NS$, $I = NS+1$ for IGV Unit: inch or cm	F 5.3
7	SC(I)	chord length of Ith stage stator $I= 1 \sim NS$, $I=NS+1$ for IGV Unit: inch or cm	F 5.3

TABLE 4.1 INDEX FOR UNIT SELECTION

IUNIT	Unit of Input data	Unit of Output Variables
1	English	English
2	Metric	Metric
3	English	Metric
4	Metric	English

Card No.	Input Data	Comment	Format
8	SBLADE(I)	number of blade for Ith stage stator. I=1∿NS, I=NS+1 for IGV	F 5.2
9	SIGUMR(I)	solidity of Ith stage rotor I = 1∿ NS	F 5.3
10	SIGUMS(I)	solidity of Ith stage stator I=1∿NS, I=NS+1 for IGV	F 5.3
11	FNF	fraction of design corrected rotor speed for a particular speed	F 8.2
12	XDIN	initial water content (mass fraction) of small droplet	F 5.3
12	ICENT	index for centrifugal calculation of small droplet ICENT = 1 when XDIN = 0.0 otherwise ICENT = 2	I1
12	XDDIN	initial water content (mass fraction) of large droplet	F 5.3
12	IICNET	index for centrifugal calculation of large droplet IICENT=1 when XDDIN=0.0 otherwise IICENT = 2	I1
13	TOG	total temperature of gas phase at compressor inlet Unit: Rankin or Kelvin	F 7.2
13	TOW	temperature of droplet at compressor inlet Unit: Rankin or Kelvin	F 7.2
13	PO	total pressure at compressor inlet Unit: lbf/ft^2 or N/m^2	F 7.2
14	DIN	initial diameter of small droplet Unit: μm	F 6.1
14	DDIN	initial diameter of large droplet Unit: μm	F 6.1

Card No.	Input Data	Comment	Format
15	FND	rotor corrected speed at design point Unit: RPM	F 7.1
15	T01D	compressor inlet temperature at design point Unit: Rankin or Kelvin	F 7.2
15	P01D	compressor inlet pressure at design point Unit: lbf/ft^2 or N/m^2	F 7.2
16	XCH4	initial methane content (mass fraction)	F 5.3
16	RHUMID	initial relative humidity Unit: per cent	F 10.5
17	FMWA	molecular weight of air	F 7.3
17	FMWV	molecular weight of steam	F 7.3
17	FMWC	molecular weight of methane	F 7.3
18	PREB	percent of water droplet that rebound after impingement on blade surface	F 5.1
18	DLIMIT	maximum diameter for small droplet Unit: μm	F 7.1
19	STAGES(I)	stager angle for Ith stage stator $I=1 \sim NS$, $I=NS+1$ for IGV Unit: degree	F 5.2
20	GAPR(I)	gap between Ith stage rotor and (I-1)th stage stator $I = 1 \sim NS$ Unit: inch or cm	F 7.5
21	GAPS(I)	gap between rotor blade and stator blade for Ith stage $I = 1 \sim NS$ Unit: inch or cm	F 7.5

Card No.	Input Data	Comment	Format
22	RRTIP(I)	blade tip radius at Ith stage rotor inlet I = 1 ∿NS Unit: inch or cm	F 6.3
23	SRTIP(I)	blade tip radius at Ith stage stator inlet I = 1 ∿NS Unit: inch or cm	F 6.3
24	IPERFM	index for stage performance calculation IPERFM=1: subroutine WICSPA is used IPERFM=2: subroutine WICSPA is used IPERFM=3: subroutine WICSPA is used	I1
24	IUNIT	index for unit IUNIT=1:Input=English,Output=English IUNIT=2:Input=Metric, Output=Metric IUNIT=3:Input=English,Output=Metric IUNIT=4:Input=Metric, Output=English	I1
25	IRAD	index for radius at which calculation is carried out IRAD = 1: performance at tip IRAD = 2: performance at mean IRAD = 3: performance at hub	I1
26	RT(I)	rotor inlet radius at which tip performance calculation is carried out I = 1 ∿NS Unit: inch or cm	F 5.3
27	RM(I)	rotor inlet radius at which mean line performance calculation is carried out I = 1 ∿NS Unit: inch or cm	F 5.3
28	RH(I)	rotor inlet radius at which hub performance calculation is carried out I = 1 ∿NS Unit: inch or cm	F 5.3
29	ST(I)	stator inlet radius at which tip performance calculation is carried out I = 1 ∿NS Unit: inch or cm	F 5.3

Card No.	Input Data	Comment	Format
30	SM(I)	$tator inlet radius at which mean line performance is carried out I=1 ∿ NS Unit: inch or cm	F 5.3
31	SH(I)	stator inlet radius at which hub performance calculation is carried out I = 1 ∿ NS Unit: inch or cm	F 5.3
32	BLOCK(I)	blockage factor for Ith stage rotor 0<BLOCK(I)< 1	F 5.3
33	BLOCKS(I)	blockage factor for Ith stage stator 0<BLOCKS(I)<1	F 5.3
34	BET1MR(I)	blade metal angle at Ith stage rotor inlet Unit: degree	F 5.2
35	BET2MR(I)	blade metal angle at Ith stage rotor outlet Unit: degree	F 5.2
36	BET1MS(I)	blade metal angle at Ith stage stator inlet Unit: degree	F 5.2
3/	BET2MS(I)	blade metal angle at Ith stage stator outlet Unit: degree	F 5.2
38	DMASS	mass flow rate at design point Unit: lb_m/s or kg/s	F 10.6
39	PR12D(I)	total pressure ratio for the Ith stage rotor at design point; I=1∿ NS	F 5.3
40	PR13D(I)	total pressure ratio for Ith stage at design point; I = 1∿ NS	F 5.3

Card No.	Input Data	Comment	Format
41	ETARD(I)	adiabatic efficiency for Ith stage rotor	F 5.3
42	SAREA(I)	stream tube area Ith stage rotor inlet Unit: ft^2 or m^2	F 10.7
43	SAREAS(I)	stream tube area for Ith stage stator inlet Unit: ft^2 or m^2	F 10.7
44	DELB1R(I)	change of blade metal angle for Ith stage rotor resetting I= 1∿ NS Unit: degree	F 5.2
45	DELB1S(I)	change of blade metal angle for Ith stage stator resetting I=1∿NS, I=NS+1 for IGV	F 5.2
46	XG1BLD(I)	amount of bleed or injection of air at Ith stage outlet I = 1∿ NS XG1BLD(I) < 0 for bleed XG1BLD(I) = 0 for no bleed or injection XG1BLD(I) > 0 for injection	F 5.3
47	XG2BLD(I)	amount of bleed or injection of steam at Ith stage outlet I= 1 ∿ NS XG2BLD(I) < 0 for bleed XG2BLD(I) = 0 for no bleed or injection XG2BLD(I) > 0 for injection	F 5.3
48	XG3BLD(I)	amount of bleed or injection of methane at Ith stage outlet I = 1 ∿ NS XG3BLD(I)< 0 for bleed XG3BLD(I) =0 for no bleed or injection XG3BLD(I) > 0 for injection	F 5.3

Card No.	Input Data	Comment	Format
49	XWBLD(I)	amount of bleed or injection of small droplet at Ith stage outlet I = 1 ∿ NS XWBLD(I) < 0 for bleed XWBLD(I) = 0 for no bleed or injection XWBLD(I) > 0 for injection	F 5.3
50	XWWBLD(I)	amount of bleed or injection of large droplet at Ith stage outlet I = 1 NS XWWBLD(I) <0 for bleed XWWBLD(I) =0 for no bleed or injection XWWBLD(I) >0 for injection	F 5.3
51	BET2SS(I)	absolute flow angle at Ith stage stator outlet I = 1 ∿ NS, I=NS1 for IGV	F 5.2
52	FAI	initial flow coefficient. The user can input FAI as many as one wants. However, one card must contain only one FAI and the last card must be 9.99999	F 7.5

CHAPTER V

OUTPUT

The user can select the units for output variables by choosing the value of the input variable IUNIT as shown in Table 4.1.

There are two kinds of output in this program code--regular output and diagnositic output. The regular output consists of four parts as follows:

(1) output of the inputed data;
(2) output of design point performance;
(3) output of stage performance; and
(4) output of overall performance.

5.1 Output of Inputed Data

All of the data inputed can be printed out at the beginning of output.

5.2 Output of Design Point Performance

5.2.1 Compressor Inlet (Design Point Performance)

At the compressor inlet, the following properties can be printed out for the design point performance:

(1) total temperature at compressor inlet: (R) or (K)
(2) total pressure at compressor inlet: (lbf/ft^2) or (N/m^2)
(3) static temperature at compressor inlet: (R) or (K)
(4) static pressure at compressor inlet:(lbf/ft^2) or (N/m^2)
(5) static density at compressor inlet: (lbm/ft^3) or (kg/m^3)
(6) acoustic speed at compressor inlet: (ft/s) or (m/s)
(7) axial velocity at compressor inlet: (ft/s) or (m/s)
(8) Mach number at compressor inlet
(9) stream tube area at compressor inlet: (ft^2) or (m^2)
(10) flow coefficient at compressor inlet

5.2.2 Stage Performance (Design Point Performance)

At the end of each stage, the following properties can be printed out for the design point performance:

(1) total temperature: (R) or (K)

(2) total pressure: (lbf/ft^2) or (N/m^2)

(3) static temperature: (R) or (K)

(4) static pressure: (lbf/ft^2) or (N/m^2)

(5) static density: (lbm/ft^3) or (kg/m^3)

(6) axial velocity: (ft/s) or (m/s)

(7) absolute velocity: (ft/s) or (m/s)

(8) relative velocity: (ft/s) or (m/s)

(9) tangential component of absolute velocity: (ft/s) or (m/s)

(10) tangential component of relative velocity: (ft/s) or (m/s)

(11) rotor wheel speed: (ft/s) or (m/s)

(12) absolute Macn number

(13) relative Mach number

(14) total temperature based on relative Mach number: (R) or (K)

(15) total pressure based on relative Mach number: (lbf/ft^2) or (N/m^2)

(16) absolute flow angle: (degree)

(17) relative flow angle: (degree)

(18) stream tube area:(ft^2) or (m^2)

(19) radius at which caculation is carried out : (ft) or (m)

(20) flow coefficient

(21) stage total pressure ratio

(22) stage adiabatic efficiency

(23) rotor total pressure ratio

(24) rotor adiabatic efficiency

(25) stage total temperature ratio

5.2.3 Overall Performance (Design Point Performance)

After all of stage performance is printed out, the following properties can be printed out.

(1) compressor inlet total temperature: (R) or (K)

(2) compressor inlet total pressure: (lbf/ft^2) or (N/m^2)
(3) corrected mass flow rate: (lbm/s) or (kg/s)
(4) overall total pressure ratio
(5) overall total temperature ratio
(6) overall adiabatic efficiency
(7) overall temperature rise: (F) or (c)
(8) relative flow angle at rotor inlet: BET1SR(I) (degree)
(9) relative flow angle at rotor outlet:BET2SR(I) (degree)
(10) incidence for rotor: AINCSR(I) (degree)
(11) deviation for rotor: ADEVSR (degree)
(12) absolute flow angle for stator inlet: BET1SS(I) (degree)
(13) absolute flow angle for stator outlet: BET2SS(I) (degree)
(14) incidence for stator : AINCSS(I) (degree)
(15) deviation for stator: ADEVSS(I) (degree)
(16) stage inlet temperature: TD(I) (R) or (K)
(17) total pressure loss coefficient for stator: OMEGS(I)
(18) total pressure loss coefficient for rotor : OMEGR(I)

5.3 Output of Stage Performance

The performance of a stage is calculated for given initial and operating conditions with respect to the gaseous phase and the water droplets. At the exit of a blade row, the four major processes associated with two phase flow, namely (a) droplet impingement process; (b) centrifugal action on droplets; (c) heat and mass transfer processes between the two phases; and (d) droplet size adjustment; are taken into account. When the stage performance parameters are corrected for the afore-mentioned four processes, then one obtains the outlet conditions from a stage. The output of stage performance consist of two parts. First the following properties can be printed out before the afore-mentioned four processes are taken into account.

(1) stage total pressure ratio
(2) stage total temperature ratio
(3) stage adiabatic efficiency
(4) stage flow coefficient
(5) axial velocity: (ft/sec) or (m/sec)
(6) rotor speed: (ft/sec) or (m/sec)

(7) total pressure: (lbf/ft^2) or (N/m^2)

(8) static pressure: (lbf/ft^2) or (N/m^2)

(9) total temperature of gas phase: (R) or (K)

(10) static temperature of gas phase: (R) or (K)

(11) static density of gas phase: (lbm/ft^3) or (kg/m^3)

(12) static density of mixture: (lbm/ft^3) or (kg/m^3)

(13) axial velocity: (ft/s) or (m/s)

(14) absolute velocity: (ft/s) or (m/s)

(15) relative velocity: (ft/s) or (m/s)

(16) blade wheel speed: (ft/s) or (m/s)

(17) tangential component of absolute velocity: (ft/s) or (m/s)

(18) tangential component of relative velocity: (ft/s) or (m/s)

(19) acoustic speed: (ft/sec) or (m/s)

(20) absolute Mach number

(21) relative Mach number

(22) flow coefficient

(23) stream tube area (ft^2) or (m^2)

(24) absolute flow angle: (degree)

(25) relative flow angle: (degree)

(26) incidence: (degree)

(27) deviation: (degree)

After the stage parameters are corrected for the afore-mentioned four processes, the following second parts of output of stage performance can be printed out.

(1) stage total pressure ratio

(2) stage total temperature ratio

(3) stage adiabatic efficiency

(4) water vapor content: XV

(5) water content of small droplet: XW

(6) water content of large droplet: XWW

(7) total water content: XWT

(8) mass fraction of dry air: XAIR

(9) mass fraction of methane: XMETAN

(10) mass fraction of gaseous phase: XGAS

(11) mass flow rate of small droplet: WMASS(lbm/s) or (Kg/S)

(12) mass flow rate of large droplet: WWMASS (lbm/s) or (Kg/S)

(13) total mass flow rate of droplet: WTMASS (lbm/s) or (Kg/S)

(14) mass flow rate of dry air: AMASS (lbm/s) or (Kg/S)

(15) mass flow rate of methane: CHMASS (lbm/s) or (Kg/S)

(16) mass flow rate of water vapor: VMASS (lbm/s) or (Kg/S)

(17) mass flow rate of gaseous phase: GMASS (lbm/s) or (kg/S)

(18) mass flow rate of mixture: TMASS (lbm/s) or (Kg/S)

(19) specific humidity: WS

(20) density of air: RHOA (lbm/ft^3) or (Kg/m^3)

(21) density of mixture: RHOM (lbm/ft^3) or (Kg/m^3)

(22) density of gaseous phase: RHOG (lbm/ft^3) or (Kg/m^3)

(23) temperature of gaseous phase: TG (R) or (K)

(24) temperature of small droplet: TW (R) or (K)

(25) temperature of large droplet: TWW (R) or (K)

(26) pressure: P (lbf/ft^2) or (N/m^2)

(27) boiling point: TB (R) or (K)

(28) dew point: TDEW (R)or (K)

5.4 Output of Overall Performance

At the end of compressor, the overall performance can be printed out. The properties to be printed out are as follows:

(1) initial flow coefficient

(2) corrected speed of compressor and fraction of design corrected speed

(3) initial water content of small droplet

(4) initial water content of large droplet

(5) initial total water content

(6) initial relative humidity

(7) initial methane content

(8) compressor inlet total temperature: (R) or (K)

(9) compressor inlet total pressure: (lbf/ft^2) or (N/m^2)

*(10) corrected mass flow rate of mixture: (lbm/s) or (Kg/S)

*(11) corrected mass flow rate of gaseous phase: (lbm/s) or (Kg/S)

(12) overall total pressure ratio

(13) overall total temperature ratio

(14) overall adiabatic efficiency

(15) overall temperature rise of gaseous phase: (F) or (c)

5.5 Diagnostic Printout

At the inlet of each stage, the flow coefficient is calcualted. If the flow coefficient gives the value of equivalent pressure ratio which is less than 1.0 or the value of stage adiavatic efficiency which is less than 0.0, the following message will appear. "FAI IS TOO BIG OR TOO SMALL AT STAGE=." If this message appears, the computation for the particular initial flow coefficient will be terminated and the next initial flow coefficient will be read.

The iterative procedure is used to determine the Mach number. If the desired accuracy can not be obtained after 50 times of iteration , the following message will appear. "M DOES NOT CONVERGE AT STAGE=." If this message appears, the final value of Mach number will be used and computation will be continued.

When the axial velocity become either higher than local acoustic speed or negative, the following message will appear: "VZ IS TOO HIGH OR TOO LOW." If this message appears, the computation for the particular initial flow coefficient will be terminated and the next initial flow coefficient will be read.

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* The mass flow rate corresponds to stream tube area specified in input data. The mass flow rate which corresponds to compressor total flow area is also printed out in the brackets.

CHAPTER VI

A TEST CASE

The application of the PURDU-WICSTK program is illustrated with a test case pertaining to the Test Compressor described in Appendix 1. The Test Compressor consists of the six axial stages of the ALLISON T63-A-5 engine compressor. The design point overall pressure ratio (mass averaged) is 2.9 with 3.0 lbm/sec of mass flow rate, and the design rotor speed is 51120 RPM.

The test case consists of the following predictions for the Test Compressor.

(i) Part I: Operation with air flow at a selected speed and throttle setting.

(ii) Part II: Operation with air-small droplet mixture flow at a selected speed and throttle setting; and

(iii) Part III: Operation with air-large droplet mixture flow at a selected speed and throttle setting.

The test case has been reproduced in Appendix 5.

6.1 Test Case Part I

The Test Case Part I demonstrates the use of the code for predicting the performance of a compressor which operates with air flow (only) at a selected speed and throttle setting. The performance prediction has been presented at the mean line of the Test Compressor.

6.1.1 Input Data

The input data for Test Case Part I are listed below as they are read in program MAIN.

Card 1:	NS = 6	
Card 2:	RRHUB(1) = 0.770 inch	
	RRHUB(2) = 1.035 inch	
	RRHUB(3) = 1.232 inch	
	RRHUB(4) = 1.378 inch	
	RRHUB(5) = 1.489 inch	
	RRHUB(6) = 1.572 inch	
Card 3:	RC(1) = 0.605 inch	
	RC(2) = 0.554 inch	
	RC(3) = 0.534 inch	
	RC(4) = 0.510 inch	
	RC(5) = 0.483 inch	
	RC(6) = 0.456 inch	
Card 4:	RBLADE(1) = 16.00	
	RBLADE(2) = 20.00	
	RBLADE(3) = 20.00	
	RBLADE(4) = 25.00	
	RBLADE(5) = 28.00	
	RBLADE(6) = 32.00	
Card 5:	STAGER(1) = 34.25 degree	
	STAGER(2) = 29.96 degree	
	STAGER(3) = 27.37 degree	
	STAGER(4) = 28.30 degree	
	STAGER(5) = 29.17 degree	
	STAGER(6) = 29.75 degree	
Card 6:	SRHUB(1) = 0.923 inch	
	SRHUB(2) = 1.145 inch	
	SRHUB(3) = 1.311 inch	
	SRHUB(4) = 1.445 inch	
	SRHUB(5) = 1.538 inch	
	SRHUB(6) = 1.580 inch	
	SRHUB(7) = 0.774 inch	

Card 7: SC(1) = 0.442 inch
SC(2) = 0.412 inch
SC(3) = 0.412 inch
SC(4) = 0.412 inch
SC(5) = 0.412 inch
SC(6) = 0.412 inch
SC(7) = 1.100 inch

Card 8: SBLADE(1) = 14.00
SBLADE(2) = 26.00
SBLADE(3) = 28.00
SBLADE(4) = 32.00
SBLADE(5) = 36.00
SBLADE(6) = 30.00
SBLADE(7) = 7.00

Card 9: SIGUMR(1) = 1.052
SIGUMR(2) = 1.120
SIGUMR(3) = 1.037
SIGUMR(4) = 1.182
SIGUMR(5) = 1.211
SIGUMR(6) = 1.283

Card 10: SIGUMS(1) = 0.640
SIGUMS(2) = 1.061
SIGUMS(3) = 1.093
SIGUMS(4) = 1.199
SIGUMS(5) = 1.311
SIGUMS(6) = 1.087
SIGUMS(7) = 0.858

Card 11: FNF = 1.00

Card 12:	XDIN	= 0.000
	ICENT	= 1
	XDDIN	= 0.000
	IICENT	= 1
Card 13:	TOG	= 518.70 R
	TOW	= 513.70 R
	PO	= 2116.80 lb_f/ft^2
Card 14:	DIN	= 20.0 μm
	DDIN	= 600.0 μm
Card 15:	FND	= 51120.0 RPM
	T01D	= 518.70 R
	P01D	= 2116.80 lb_f/ft^2
Card 16:	XCH4	= 0.000
	RHUMID	= 0.00001 per cent
Card 17:	FMWA	= 28.964
	FMWV	= 18.016
	FMWX	= 16.043
Card 18:	PREB	= 50.00 per cent
	DLIMIT	= 100.0 μm
Card 19:	STAGES(1)	= 23.67 degree
	STAGES(2)	= 25.62 degree
	STAGES(3)	= 26.94 degree
	STAGES(4)	= 28.41 degree
	STAGES(5)	= 29.82 degree
	STAGES(6)	= 38.99 degree
	STAGES(7)	= 10.99 degree

Card 20:	GAPR(1)	= 0.125 inch
	GAPR(2)	= 0.125 inch
	GAPR(3)	= 0.125 inch
	GAPR(4)	= 0.125 inch
	GAPR(5)	= 0.125 inch
	GAPR(6)	= 0.125 inch
Card 21:	GAPS(1)	= 0.125 inch
	GAPS(2)	= 0.125 inch
	GAPS(3)	= 0.125 inch
	GAPS(4)	= 0.125 inch
	GAPS(5)	= 0.125 inch
	GAPS(6)	= 0.125 inch
Card 22:	RRTIP(1)	= 2.16 inch
	RRTIP(2)	= 2.16 inch
	RRTIP(3)	= 2.16 inch
	RRTIP(4)	= 2.16 inch
	RRTIP(5)	= 2.16 inch
	RRTIP(6)	= 2.16 inch
Card 23:	SRTIP(1)	= 2.16 inch
	SRTIP(2)	= 2.16 inch
	SRTIP(3)	= 2.16 inch
	SRTIP(4)	= 2.16 inch
	SRTIP(5)	= 2.16 inch
	SRTIP(6)	= 2.16 inch
Card 24:	IPERFM	= 2
	IUNIT	= 1
Card 25:	IRAD	= 2

Card 26:	RT(1)	= 2.149 inch
	RT(2)	= 2.151 inch
	RT(3)	= 2.148 inch
	RT(4)	= 2.149 inch
	RT(5)	= 2.149 inch
	RT(6)	= 2.147 inch
Card 27:	RM(1)	= 1.426 inch
	RM(2)	= 1.575 inch
	RM(3)	= 1.642 inch
	RM(4)	= 1.722 inch
	RM(5)	= 1.789 inch
	RM(6)	= 1.836 inch
Card 28:	RH(1)	= 0.781 inch
	RH(2)	= 1.056 inch
	RH(3)	= 1.252 inch
	RH(4)	= 1.411 inch
	RH(5)	= 1.533 inch
	RH(6)	= 1.621 inch
Card 29:	ST(1)	= 0.934 inch
	ST(2)	= 1.152 inch
	ST(3)	= 1.318 inch
	ST(4)	= 1.453 inch
	ST(5)	= 1.548 inch
	ST(6)	= 1.592 inch
Card 30:	SM(1)	= 1.502 inch
	SM(2)	= 1.573 inch
	SM(3)	= 1.637 inch
	SM(4)	= 1.712 inch
	SM(5)	= 1.766 inch
	SM(6)	= 1.784 inch

Card 31:	SH(1)	= 2.147 inch
	SH(2)	= 2.138 inch
	SH(3)	= 2.127 inch
	SH(4)	= 2.123 inch
	SH(5)	= 2.118 inch
	SH(6)	= 2.100 inch
Card 32:	BLOCK(1)	= 0.983
	BLOCK(2)	= 0.976
	BLOCK(3)	= 0.967
	BLOCK(4)	= 0.949
	BLOCK(5)	= 0.923
	BLOCK(6)	= 0.902
Card 33:	BLOCKS(1)	= 0.978
	BLOCKS(2)	= 0.966
	BLOCKS(3)	= 0.945
	BLOCKS(4)	= 0.928
	BLOCKS(5)	= 0.908
	BLOCKS(6)	= 0.863
Card 34:	BET1MR(1)	= 42.72 degree
	BET1MR(2)	= 42.74 degree
	BET1MR(3)	= 41.62 degree
	BET1MR(4)	= 42.85 degree
	BET1MR(5)	= 44.00 degree
	BET1MR(6)	= 45.07 degree
Card 35:	BET2MR(1)	= 25.79 degree
	BET2MR(2)	= 17.17 degree
	BET2MR(3)	= 13.12 degree
	BET2MR(4)	= 13.76 degree
	BET2MR(5)	= 14.33 degree
	BET2MR(6)	= 14.43 degree

Card 36: BET1MS(1) = 35.15 degree
BET1MS(2) = 40.11 degree
BET1MS(3) = 43.36 degree
BET1MS(4) = 45.00 degree
BET1MS(5) = 46.31 degree
BET1MS(6) = 48.71 degree
BET1MS(7) = 0.00 degree

Card 37: BET2MS(1) = 12.19 degree
BET2MS(2) = 11.13 degree
BET2MS(3) = 10.51 degree
BET2MS(4) = 11.81 degree
BET2MS(5) = 13.32 degree
BET2MS(6) = 29.28 degree
BET2MS(7) = 21.99 degree

Card 38: DMASS = 0.375538 lbm/sec

Card 39: PR12D(1) = 1.154
PR12D(2) = 1.165
PR12D(3) = 1.221
PR12D(4) = 1.237
PR12D(5) = 1.230
PR12D(6) = 1.215

Card 40: PR13D(1) = 1.152
PR13D(2) = 1.159
PR13D(3) = 1.213
PR13D(4) = 1.228
PR13D(5) = 1.221
PR13D(6) = 1.208

Card 41: ETARD(1) = 0.966
ETARD(2) = 0.966
ETARD(3) = 0.968
ETARD(4) = 0.965
ETARD(5) = 0.962
ETARD(6) = 0.954

Card 42: SAREA(1) = 0.0103647 ft^2
SAREA(2) = 0.0092977 ft^2
SAREA(3) = 0.0080300 ft^2
SAREA(4) = 0.0069214 ft^2
SAREA(5) = 0.0059094 ft^2
SAREA(6) = 0.0051110 ft^2

Card 43: SAREAS(1) = 0.0098704 ft^2
SAREAS(2) = 0.0084051 ft^2
SAREAS(3) = 0.0070775 ft^2
SAREAS(4) = 0.0060735 ft^2
SAREAS(5) = 0.0052626 ft^2
SAREAS(6) = 0.0046691 ft^2
SAREAS(7) = 0.0105669 ft^2

Card 44: DELB1R(1) = 0.00
DELB1R(2) = 0.00
DELB1R(3) = 0.00
DELB1R(4) = 0.00
DELB1R(5) = 0.00
DELB1R(6) = 0.00

Card 45: DELB1S(1) = 0.00
DELB1S(2) = 0.00
DELB1S(3) = 0.00
DELB1S(4) = 0.00
DELB1S(5) = 0.00
DELB1S(6) = 0.00

Card 46: XG1BLD(1) = 0.000
XG1BLD(2) = 0.000
XG1BLD(3) = 0.000
XG1BLD(4) = 0.000
XG1BLD(5) = 0.000
XG1BLD(6) = 0.000

Card 47: XG2BLD(1) = 0.000
XG2BLD(2) = 0.000
XG2BLD(3) = 0.000
XG2BLD(4) = 0.000
XG2BLD(5) = 0.000
XG2BLD(6) = 0.000

Card 48: XG3BLD(1) = 0.000
XG3BLD(2) = 0.000
XG3BLD(3) = 0.000
XG3BLD(4) = 0.000
XG3BLD(5) = 0.000
XG3BLD(6) = 0.000

Card 49: XWBLD(1) = 0.000
XWBLD(2) = 0.000
XWBLD(3) = 0.000
XWBLD(4) = 0.000
XWBLD(5) = 0.000
XWBLD(6) = 0.000

Card 50: XWWBLD(1) = 0.000
XWWBLD(2) = 0.000
XWWBLD(3) = 0.000
XWWBLD(4) = 0.000
XWWBLD(5) = 0.000
XWWBLD(6) = 0.000

Card 51: BET2SS(1) = 21.89 degree
BET2SS(2) = 19.09 degree
BET2SS(3) = 19.33 degree
BET2SS(4) = 20.18 degree
BET2SS(5) = 21.15 degree
BET2SS(6) = 34.86 degree
BET2SS(7) = 15.61 degree

Card 52: FAI = 0.5000

Card 53: FAI = 9.99999

6.1.2 Output

The output for Test Case Part I is presented in Appendix 5. The details of the output obtained are described in Chapter V.

6.2 Test Case Part II

The Test Case Part II demonstrates the use of the code for predicting the performance of a compressor which operates with air-small droplet mixture flow at a selected speed and throttle setting. The water content of small droplet has been specified as four per cent by weight. The performance prediction has been presented at the mean line of the Test Compressor.

6.2.1 Input Data

The input data for Test Case Part II are the same as those for Test Case Part I except in regard to the following.

Card 12: XDIN = 0.040
ICENT = 2
XDDIN = 0.000
IICENT = 1

6.2.2 Output

The output for Test Case Part II is presented in Appendix 5. The details of the output obtained are described in Chapter V.

6.3 Test Case Part III

The Test Case Part III demonstrates the use of the code for predicting the performance of a compressor which operates with air-large droplet mixture flow at a selected speed and throttle setting. The water content of large droplet has been specified as four per cent by weight. The performance prediction has been presented at the mean line of the Test Compressor.

6.3.1 Input Data

The input data for Test Case Part III are the same as those for Test Case Part I except in regard to the following.

Card 12: XDIN = 0.000
ICENT = 1
XDDIN = 0.040
IICENT = 2

6.3.2 Output

The output for Test Case Part III is presented in Appendix 5. The details of the output properties are described in Chapter V.

FIGURES

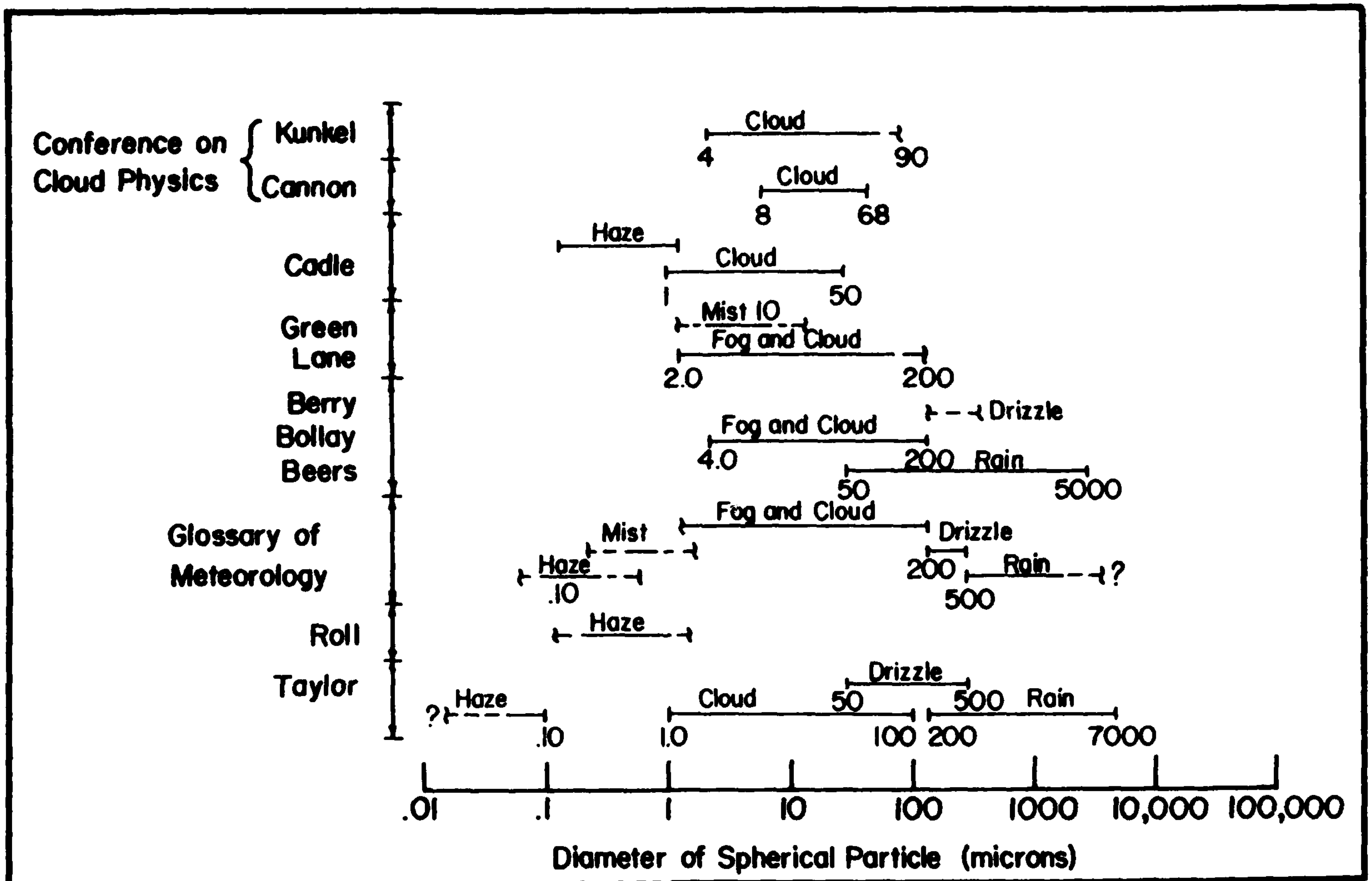

Fig. 1.1 Atmospheric Particle Size Ranges

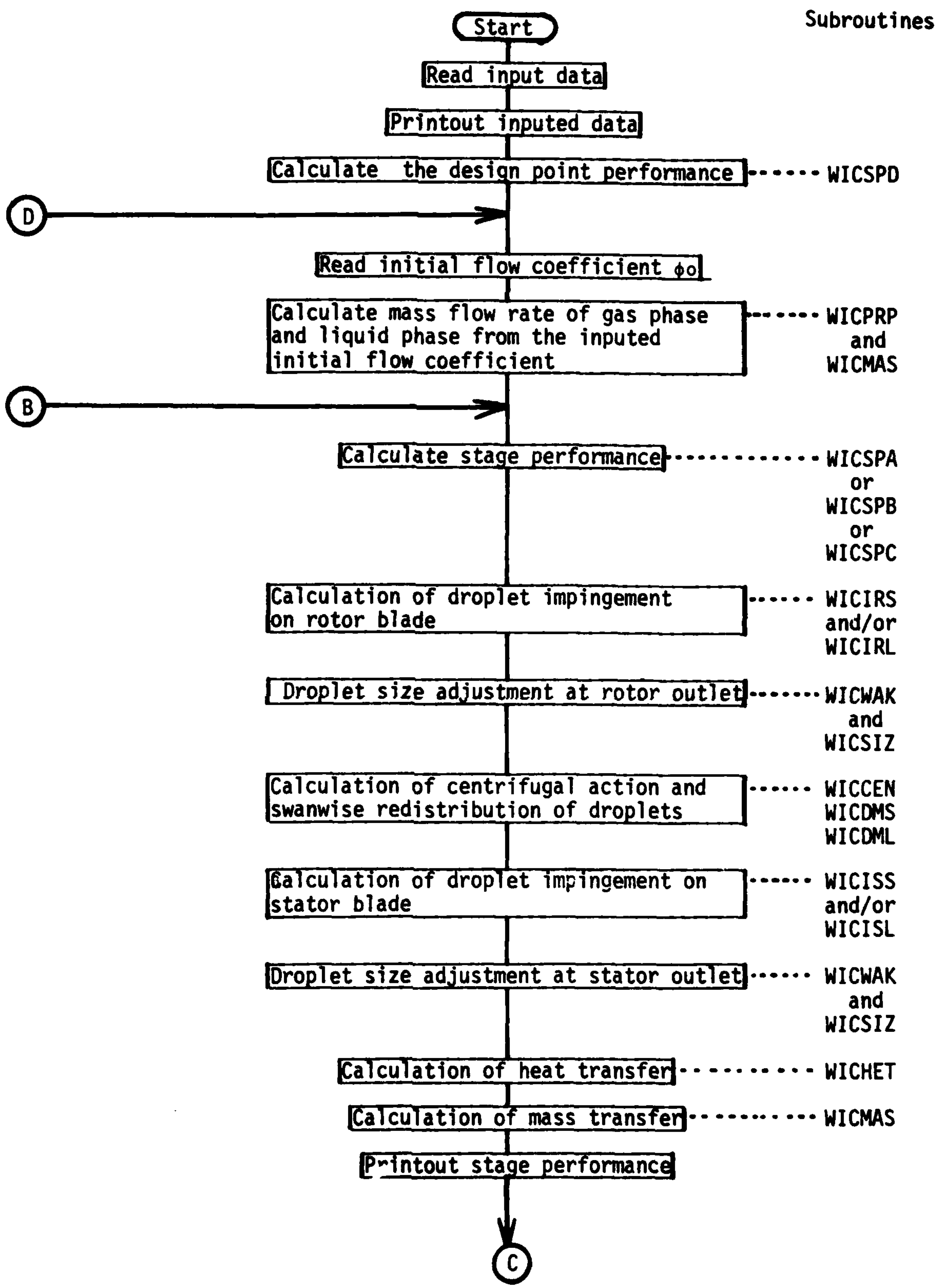

Figure 2.1 Flow Chart of of Overall Program Structure

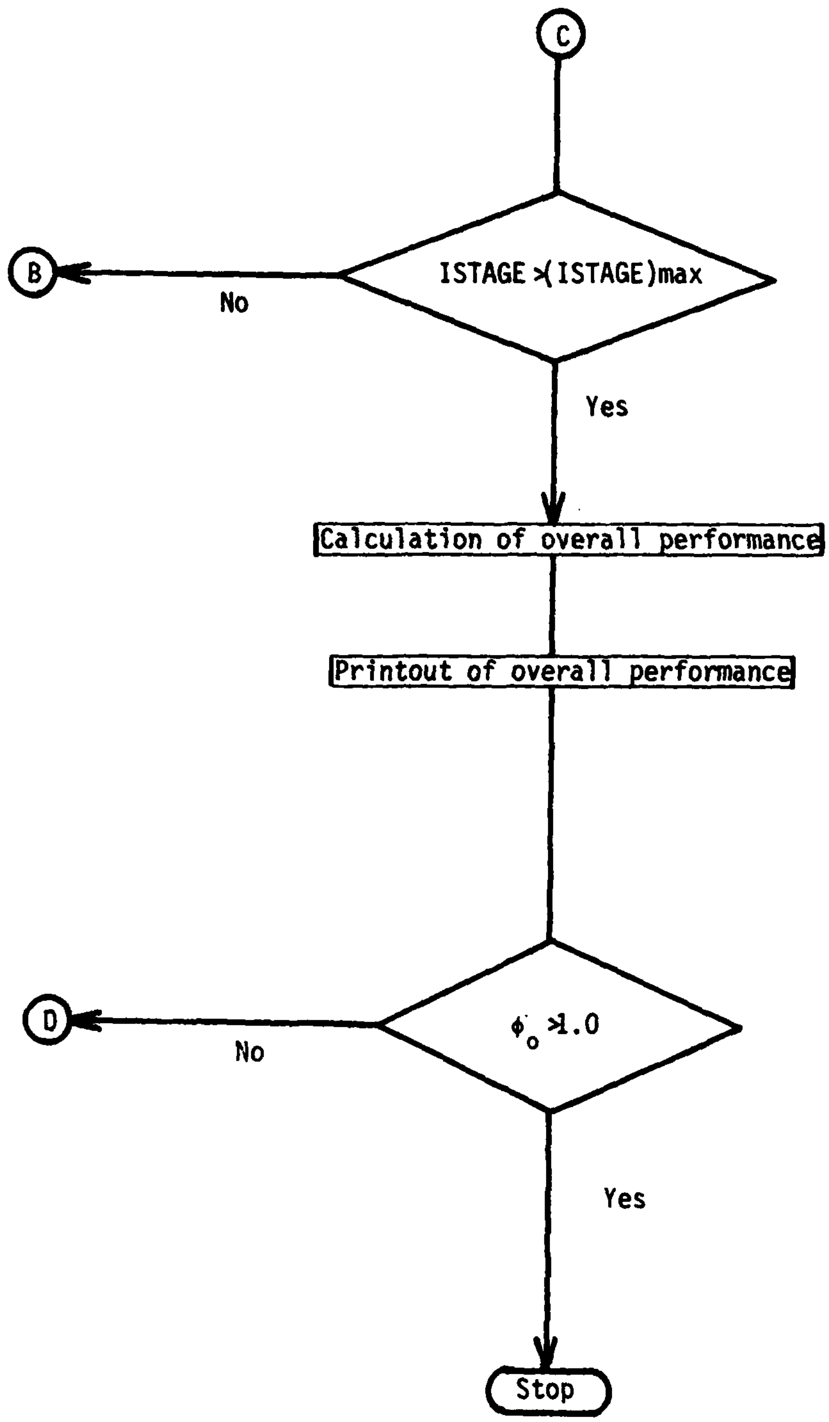

Figure 2.1 Flow Chart of Overall Program Structure (Continued)

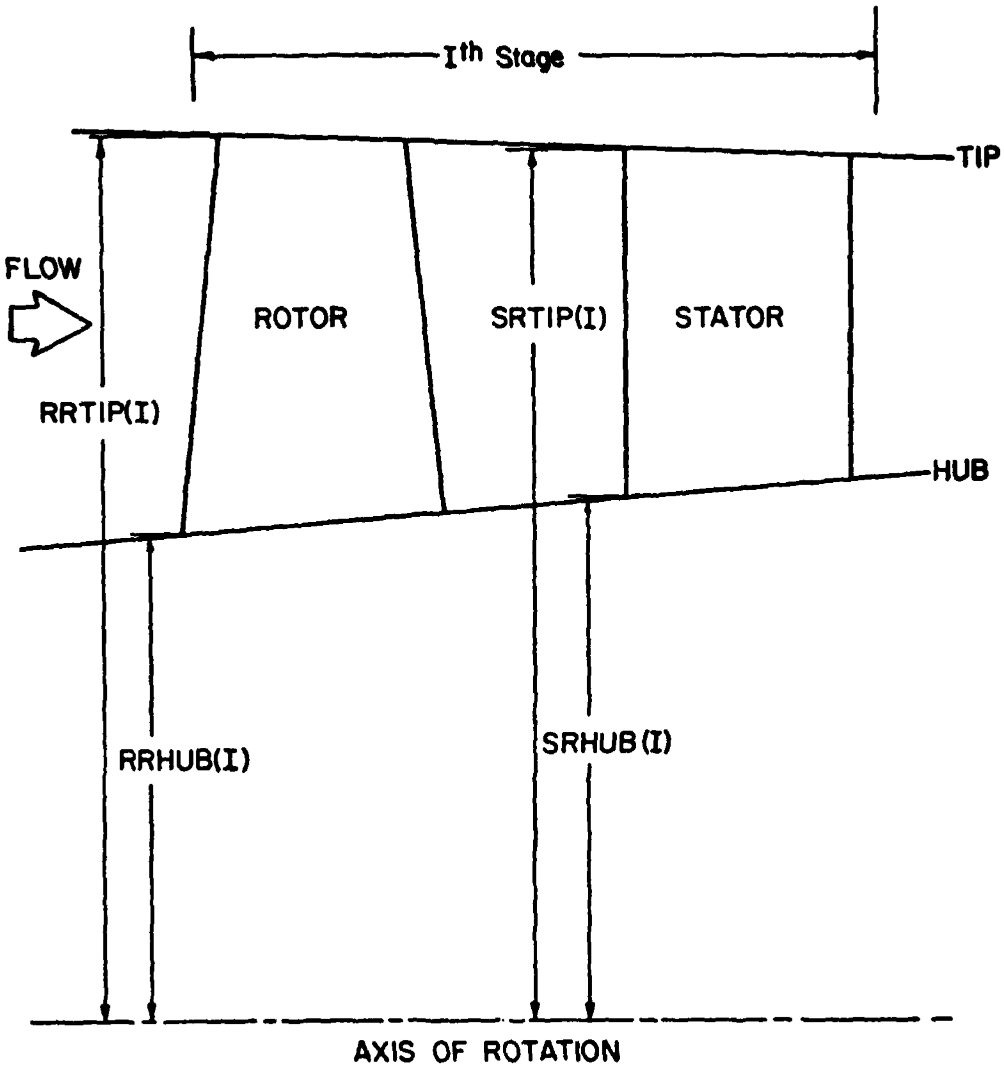

Fig. 4.1 Geometry of Compressor Stage

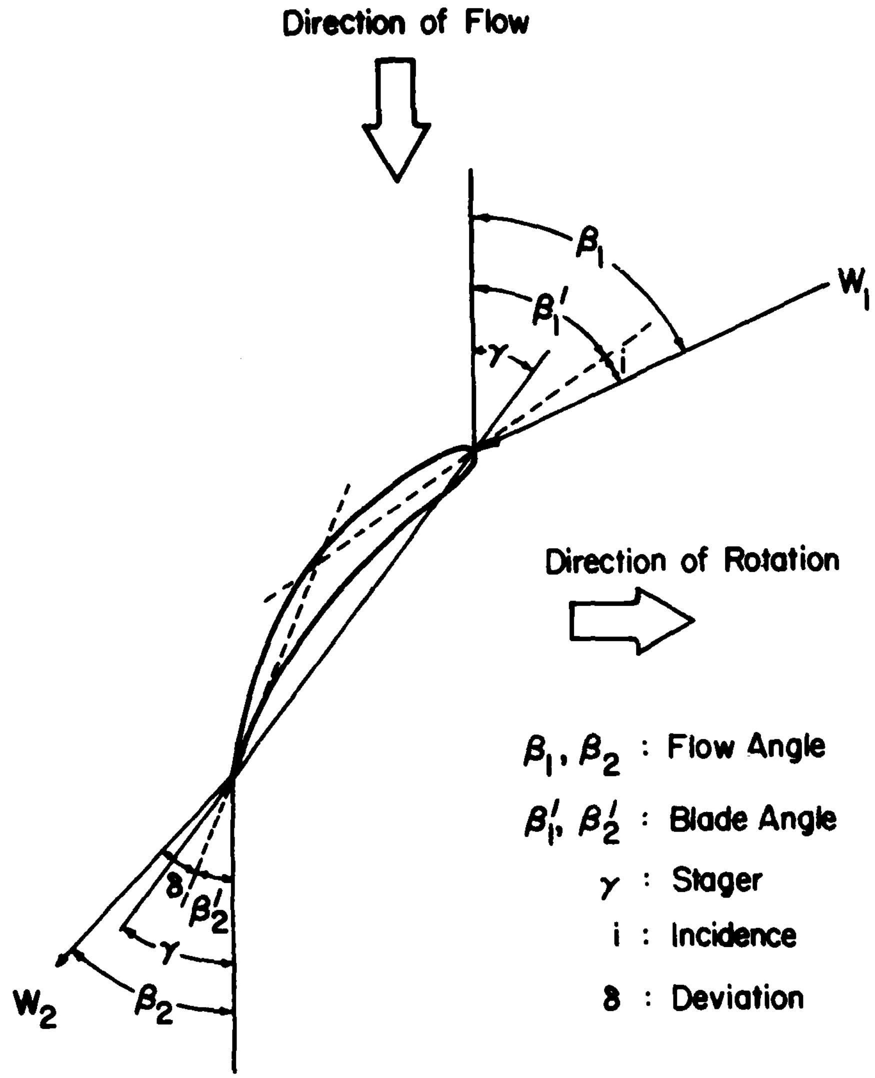

Fig. 4.2 Angles Associated With a Typical Rotor Blade Element

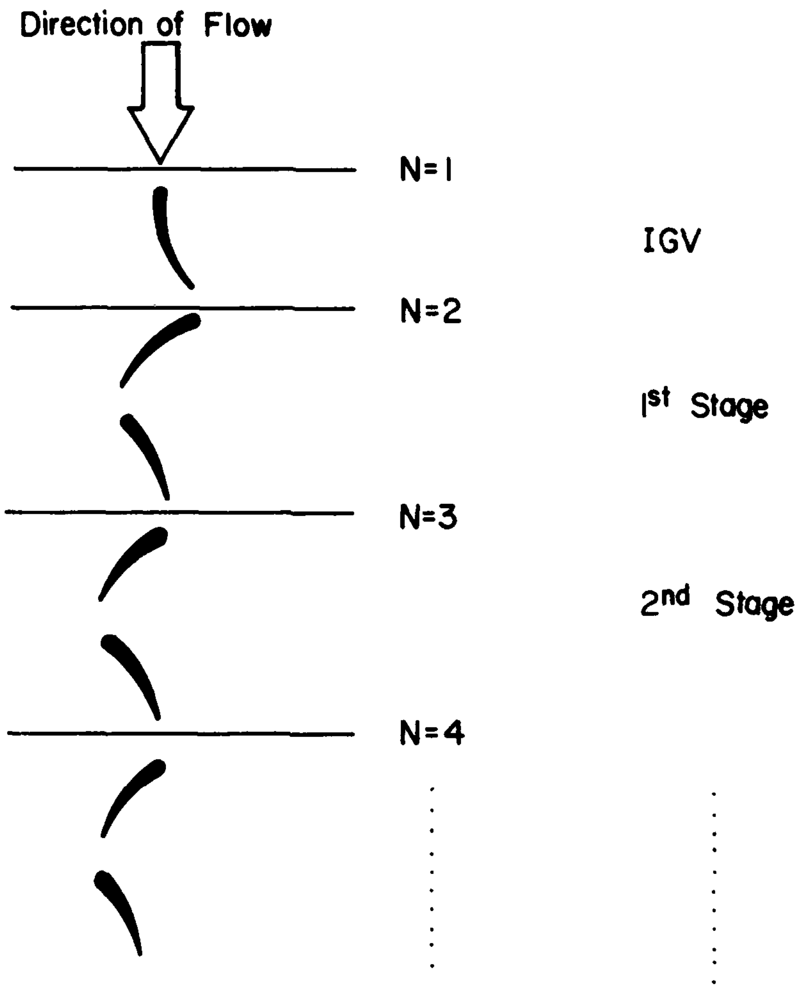

Fig. 5.1 Station Number in Compressor Stages

APPENDIX 1

DETAIL OF TEST COMPRESSOR AND DRIVE ENGINE

1. Drive Engine

A T63-A-5 engine is used to drive the Test Compressor. The specifications, limits, and performance ratings for the Drive Engine are as follows:

Design power output: 250 shp
Ram power rating: 275 shp

Design speeds:

Gas producer	51120 rpm (100%)
Power turbine	35000 rpm (100%)
Power output shaft	6000 rpm

Fuel Specification : MIL-J-5624E(JP-4)

The Drive Engine power turbine drives the Test Compressor through mechanical gearing. The power turbine speed has been increased to an output of 9,643 rpm at 100 per cent speed from the normal rating of 6,000 rpm. The Test Compressor is operated at 110 per cent (56,251.7 rpm) while the engine operates at 100 per cent or 51,120 rpm. One power turbine tachometer is used to monitor the Test Compressor speed. The ratio of the tachometer speed to the Test Compressor speed is 0.119676.

2. Test Compressor

The Test Compressor consists of the six axial stages of the ALLISON T63-A-5 engine compressor. The Test Compressor has been designed and built such that various stages of the compressor can be

assembled and tested. Thus the first two, the intermediate two or the last two stages can be tested if desired, as well as the unit with all of the six stages. Only the 6-stage unit has been used in the current tests.

The first stage of the Test Compressor is preceded by an inlet guide vane row which imparts swirl to the inlet air. The relative Mach number of the incoming air at the rotor inlet is thereby reduced as far as permissible without causing inlet blockage. The axial component features unshrouded rotors, cantilever stators, and double circular arc blading in all stages. The values of T-63 compressor design velocity diagram are presented in Table A.1.1. Table A.1.3 and A.1.4 present the hardware geometry and aerodynamic design data for rotor and stator, respectively.

Figure A.1.1. to Figure A.1.6 show the stage performance characteristics of Test Compressor supplied by the manufacturer. In each of the figures, the equivalent pressure ratio, ψ , equivalent temperature ratio, τ, and stage adiabatic efficiency, η, are presented in terms of flow coefficient, ϕ. The definitions of these parameters are as follows:

(i) flow coefficient: ϕ

$$\phi = V_z/U_{tip}$$

(ii) equivalent pressure ratio: ψ

$$\psi = \left\{ \left(\frac{U_{tip}^2}{T_{01}}\right)_D \cdot \left(\frac{T_{01}}{U_{tip}^2}\right) \left[\left(\frac{P_{02}}{P_{01}}\right)^{(\gamma-1)/\gamma} -1 \right] + 1 \right\}^{\gamma/(\gamma-1)}$$

(iii) equivalent temperature ratio: τ

$$\tau = \left(\frac{U_{tip}}{T_{01}}\right)_D^2 \cdot \left(\frac{\Delta T_0}{U_{tip}^2}\right)$$

TABLE A.1.1

Test Compressor Design Velocity Diagram Values

Stage	1	2	3	4	5	6	
R	2.161	2.161	2.161	2.161	2.161	2.161	
U	963.5	963.5	963.5	963.5	963.5	963.5	
V_{z1}	508.4	544.1	547.0	554.9	554.1	543.7	↑
$V_{\theta 1}$	236.5	310.0	365.1	349.3	338.8	338.8	
$W_{\theta 1}$	727.0	653.5	598.4	614.2	624.7	629.9	Rotor Inlet
α_1	25.0	29.7	33.7	32.2	31.6	31.5	
β_1	54.9	50.3	47.6	47.9	48.5	49.3	
M_{1abs}	0.513	0.56[illegible]	0.578	0.560	0.538	0.512	
M_{1rel}	0.812	0.765	0.713	0.707	0.692	0.658	↓
V_{z2}	507.0	554.9	551.0	554.5	548.9	544.6	↑
$V_{\theta 2}$	405.2	501.3	598.8	614.6	625.1	630.3	
$W_{\theta 2}$	558.3	462.2	364.7	348.9	338.4	333.2	Rotor Outlet
α_2	38.6	42.1	47.4	47.9	48.7	49.2	
β_2	47.8	39.8	33.6	32.2	31.7	31.5	
M_{2abs}	0.588	0.665	0.706	0.698	0.680	0.660	
M_{2rel}	0.683	0.643	0.574	0.552	0.528	0.506	↓

Note: Symbols for Table A.1.1 are provided in Table A.1.2.

TABLE A.1.2

Symbols for Test Compressor Design Velocity Diagram Values

R	Radius, inches
U	Rotor speed at R, ft/sec.
V_z	Air axial velocity, ft/sec.
V_θ	Air absolute tangential velocity, ft/sec.
W_θ	Air relative tangential velocity, ft/sec.
α	Air absolute flow angle, degrees
β	Air relative flow angle, degrees
M	Mach number
Subscript	
1	rotor inlet
2	rotor outlet
abs	absolute
rel	relative

TABLE A.1.3

Test Compressor Design Data (Rotor)

Stage		1	2	3	4	5	6
Radius	R	2.161	2.161	2.161	2.161	2.161	2.161
Camber Angle	θ	22.6	15.9	18.0	19.7	20.9	22.0
Stagger	γ	46.1	42.3	36.5	36.1	36.0	36.3
Incidence	i	0.0	2.0	2.0	2.0	2.0	2.0
Deviation	δ	7.3	5.4	6.0	6.0	6.1	6.2
Chord	c	0.605	0.554	0.534	0.510	0.483	0.456
Solidity	σ	0.713	0.815	0.787	0.941	0.997	1.075
Max. Thickness	t	0.036	0.039	0.037	0.036	0.034	0.032
Thickness-Chord Ratio	t/c	0.060	0.070	0.070	0.070	0.070	0.070
No. of Blades	n	16	20	20	25	28	32

Note: R, c, t in [inches] and θ, γ, δ, i in [degrees]

TABLE A.1.4

Test Compressor Design Data (Stator)

Stage		IGV	1	2	3	4	5	6
Radius	R	2.161	2.161	2.161	2.161	2.161	2.161	2.161
Camber Angle	θ	31.7	22.4	25.6	26.2	24.4	24.7	17.3
Stagger	γ	-15.9	31.3	36.3	36.6	36.8	37.4	42.6
Incidence	i	0.0	-2.0	-2.0	-2.0	-2.0	-2.0	-2.0
Deviation	δ	6.7	9.6	5.2	8.0	7.9	7.5	5.6
Chord	c	1.395	0.442	0.412	0.412	0.412	0.412	0.412
Solidity	σ	0.719	0.456	0.789	0.850	0.972	1.093	0.910
Max. Thickness	t	0.170	0.040	0.025	0.025	0.025	0.025	0.025
Thickness-Chord Ratio	t/c	0.122	0.09	0.06	0.06	0.06	0.06	0.06
No. of Blades	n	7	14	26	28	32	36	30

Note: R, c, t in [inches] and θ, γ, δ, i in [degrees]

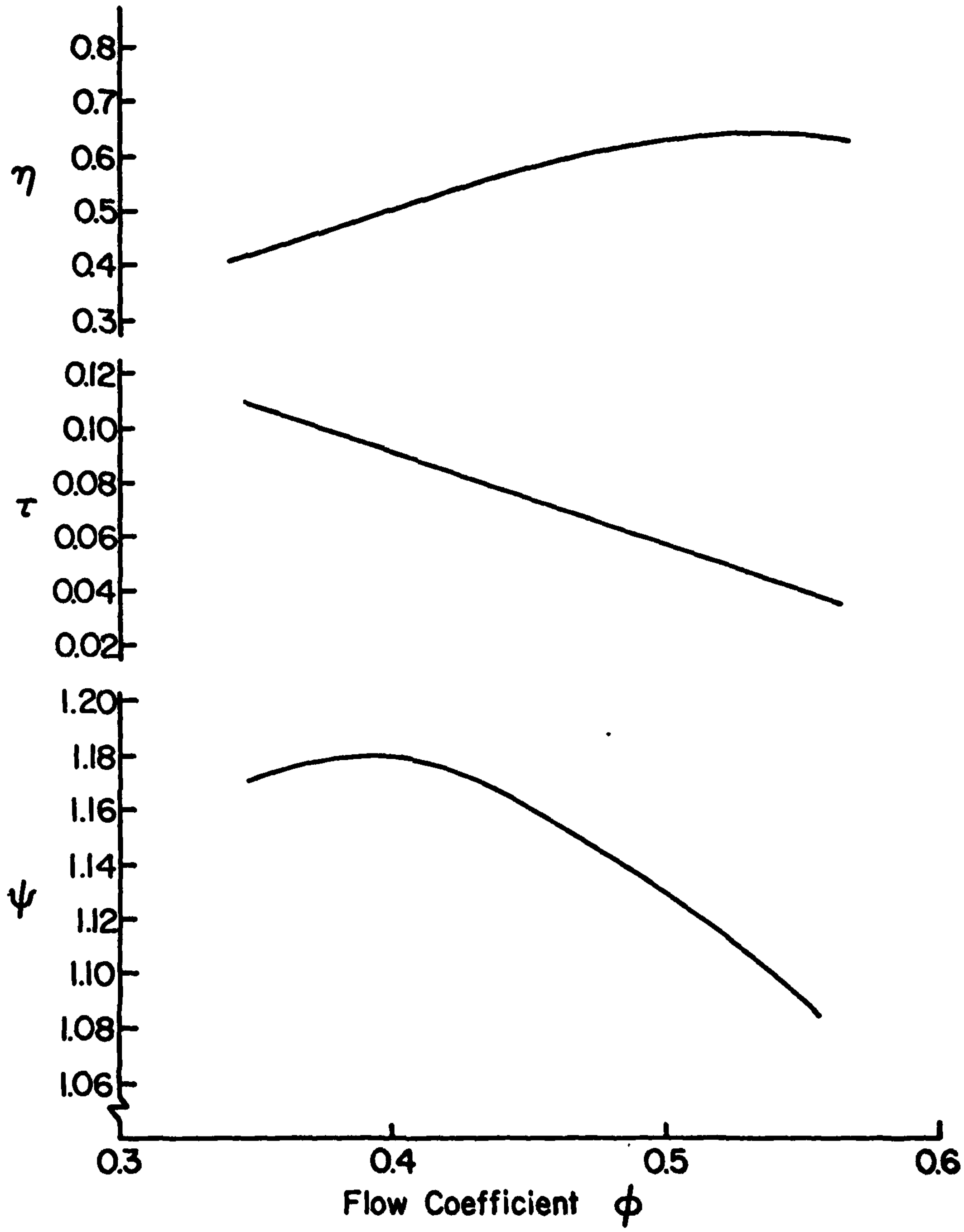

Fig. A.1.1 Performance Characteristics of Test Compressor (1st Stage)

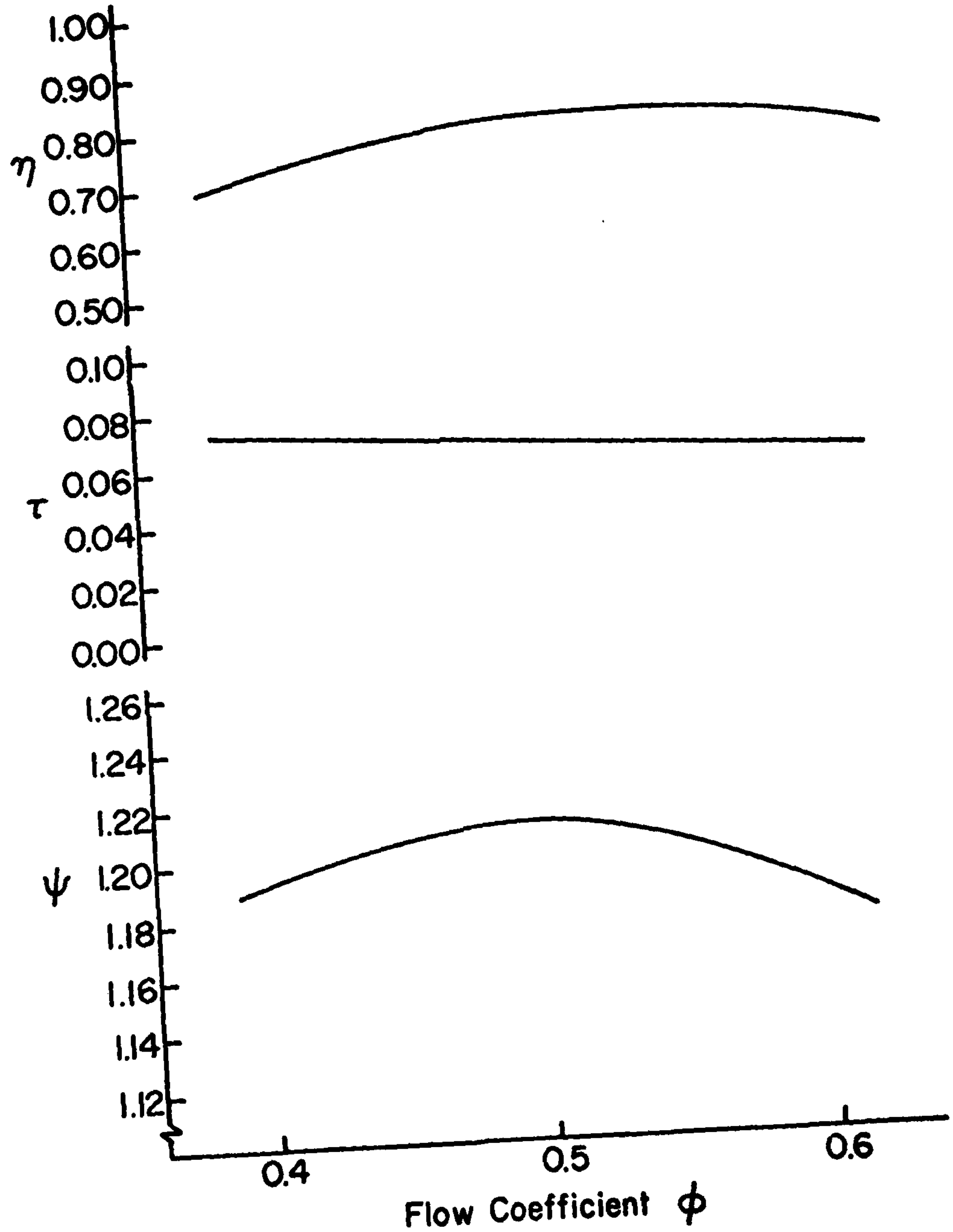

Fig. A.1.2 Performance Characteristics of Test Compressor (2nd Stage)

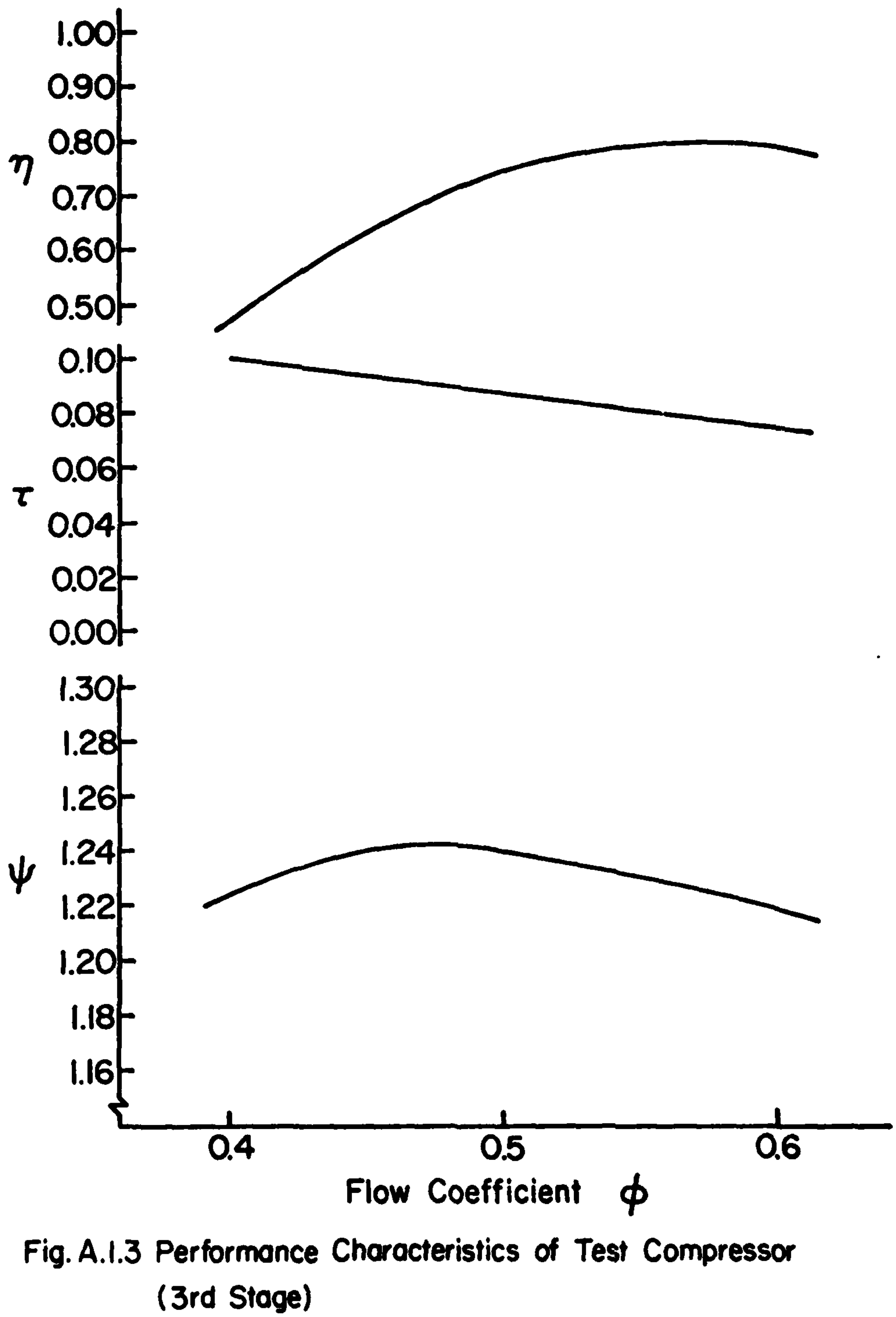

Fig. A.1.3 Performance Characteristics of Test Compressor (3rd Stage)

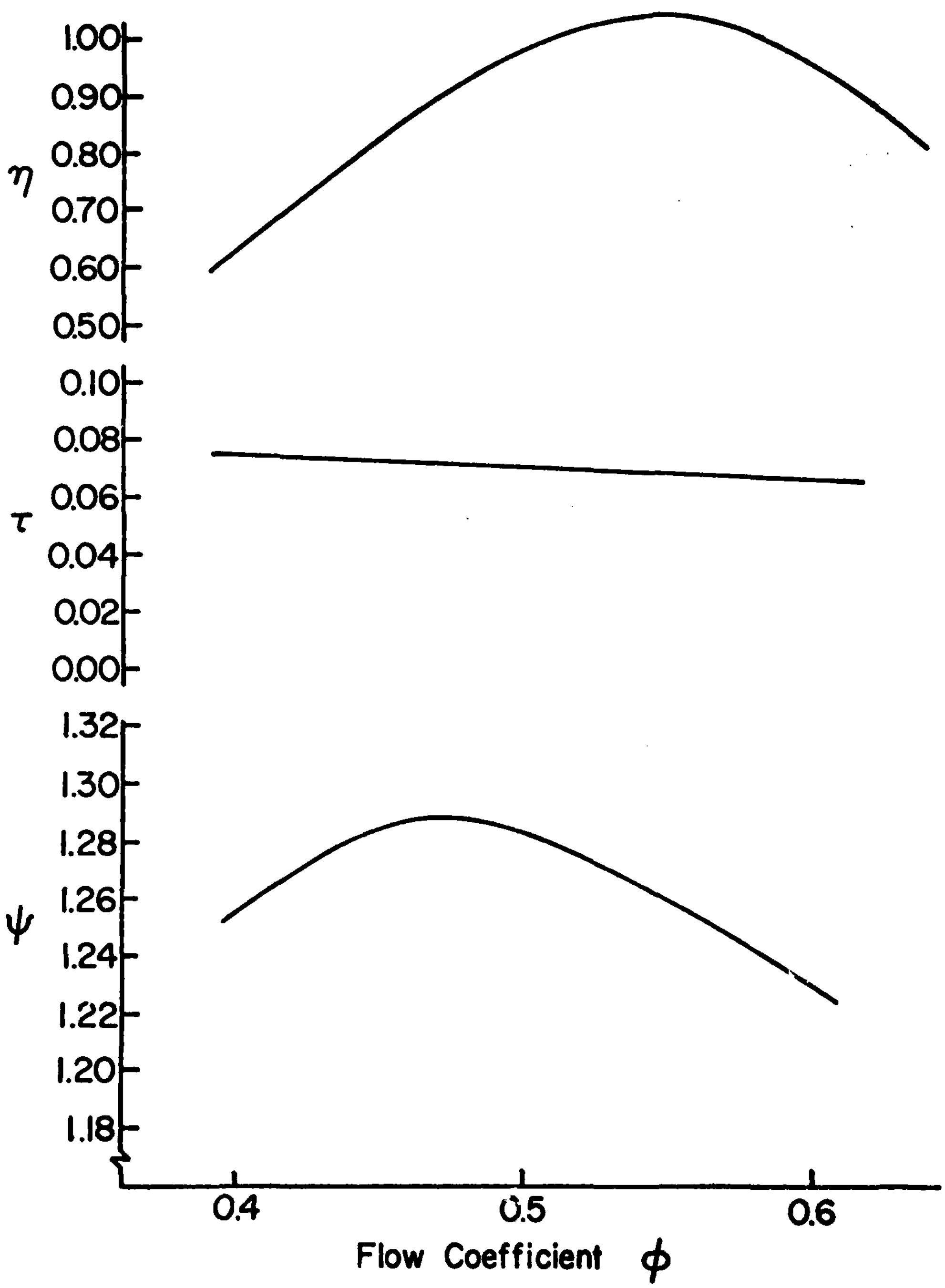

Fig. A.1.4 Performance Characteristics of Test Compressor (4th Stage)

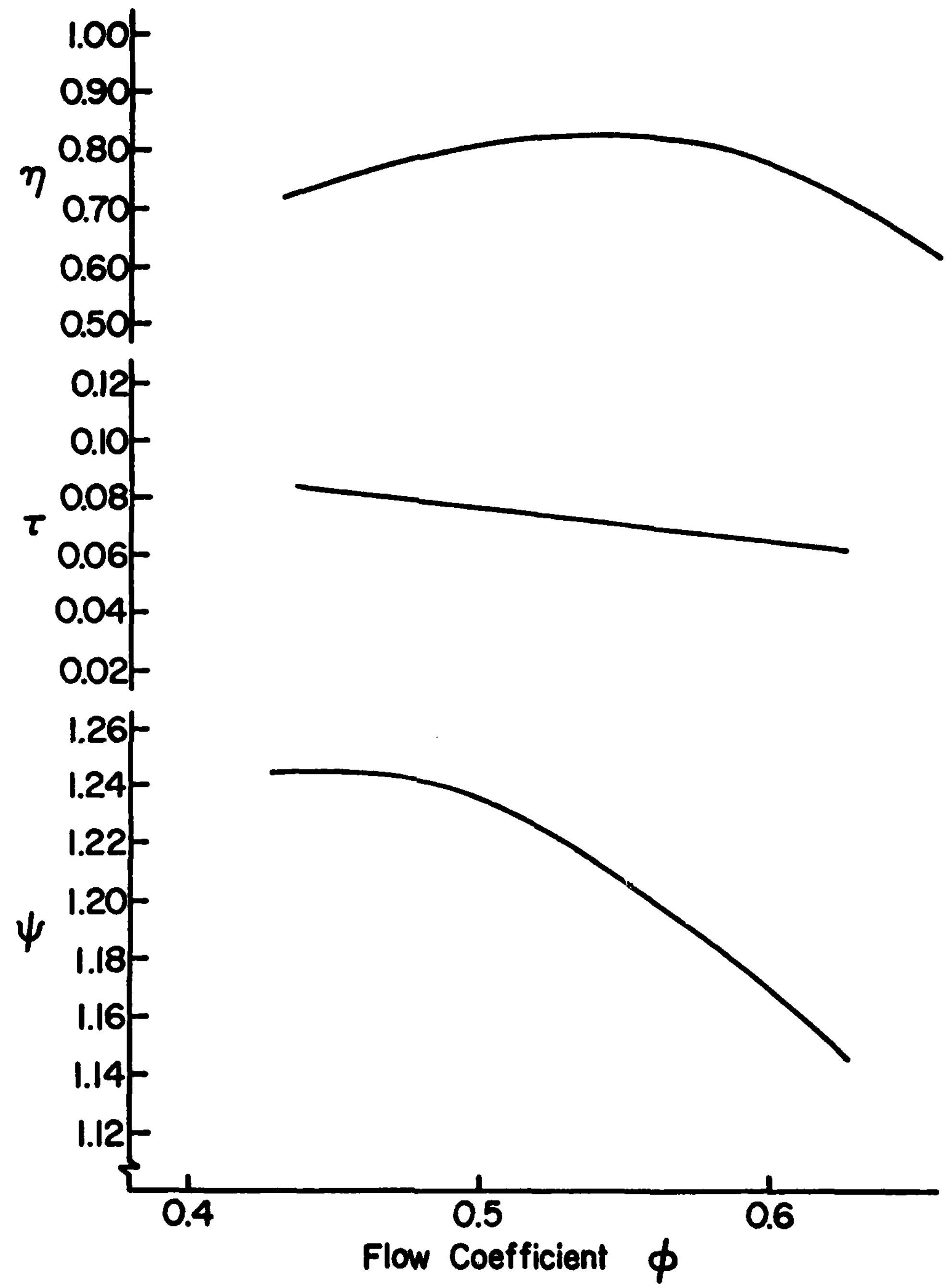

Fig. A.1.5 Performance Characteristics of Test Compressor (5th Stage)

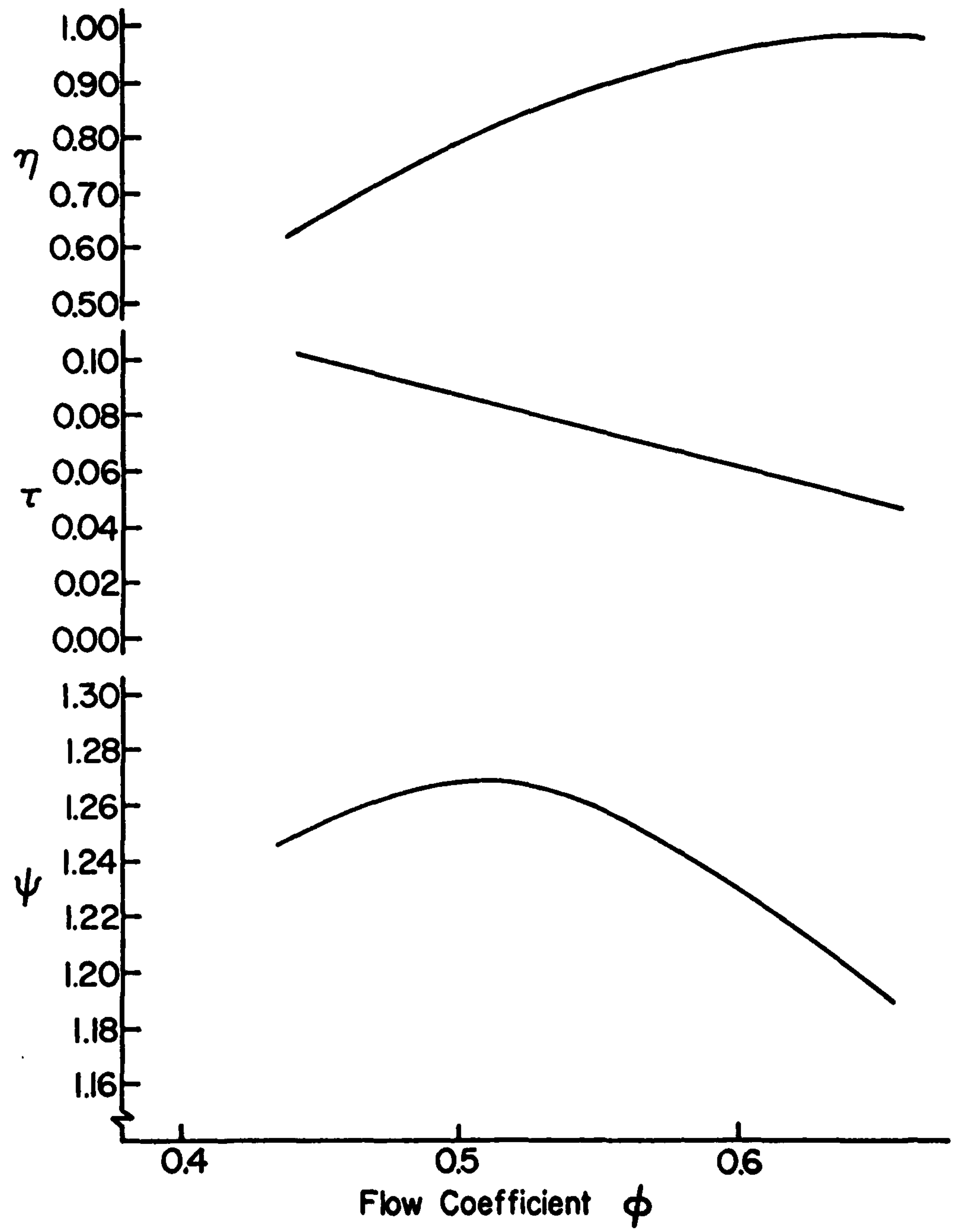

Fig. A.1.6 Performance Characteristics of Test Compressor (6th Stage)

(iv) stage adiabatic efficiency: η

$$\eta = T_{01}\left[\left(\frac{P_{02}}{P_{01}}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]\frac{1}{\Delta T_0} = (\psi^{\frac{\gamma-1}{\gamma}} - 1)/\tau$$

where ΔT_0 is stage total temperature rise, P_0 total pressure, T_0 total temperature, V_z axial velocity, U_{tip} blade tip wheel speed, γ specific heat ratio. The subscripts 1 and 2 mean inlet and outlet, respectively, and D design value.

Figure A.1.7 shows overall performance characteristics of Test Compressor supplied by the manufacturer. The performance parameters are the following:

(1) Corrected mass flow rate $= \frac{\dot{m}\sqrt{\theta}}{\delta}$

where $\dot{m}$ = mass flow rate

T_{01} = compressor inlet pressure

P_{01} = compressor inlet temperature

θ = T_{01}/T_{ref}

δ = P_{01}/P_{ref}

T_{ref} = $58.7^{o}F(15.2^{o}C)$

P_{ref} = 14.7 psi ($1.0132 \times 10^5 N/m^2$)

(2) Corrected speed $= \frac{N}{\sqrt{\theta}}$

where N = rotor speed (RPM)

(3) Overall total pressure ratio = P_{02}/P_{01}

where P_{01} = compressor inlet total pressure

P_{02} = compressor outlet total pressure

(4) Overall adiabatic efficiency $= \eta = \frac{T_{01}}{\Delta T_0}\left[\left(\frac{P_{02}}{P_{01}}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]$

where T_{01} = compressor inlet total temperature

ΔT_0 = compressor total temperature rise

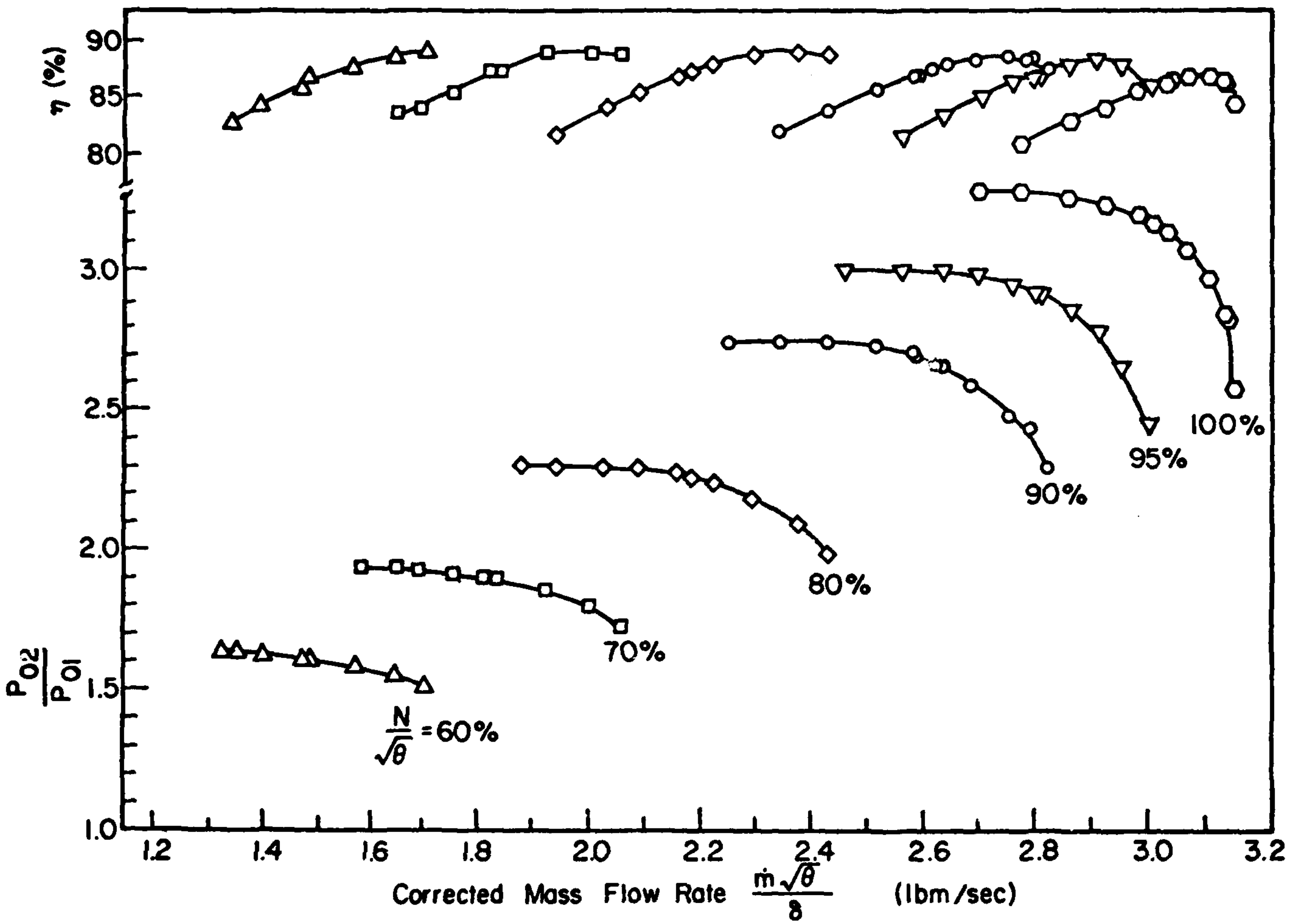

Fig. A.I.7 Overall Performance of Test Compressor

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EFFECT OF WATER ON AXIAL FLOW COMPRESSORS. PART I. ANALYSIS AND--ETC(U)
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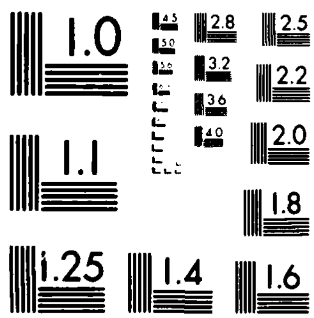

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

P_{02}/P_{01} = overall total pressure ratio

γ = ratio of specific heats

3. Limitations

The Test Compressor is driven, through a mechanical gear train, by the power turbine of the Drive Engine. The 6-stage Test Compressor has been utilized in the past for up to 30 hours. The available lifetime for further use of that Test Compressor has been uncertain.

The Test Compressor has a plastic coating on the casing that supports the stator blade rings. The mechanical and thermal strength of the coating has been uncertain since the casing was built over ten years ago and may have aged. At design point, the Test Compressor temperature rise is about 192°F, (106°C) when the inlet-air temperature is 58.7°F, (15.2°C). A casing has been replaced by a second casing during preliminary testing.

The throttle regulating the Test Compressor mass flow at any given speed of operation consists of a conical center piece that can be set at any desired location concentrically in a diverging section which is then opened to atmospheric conditions following a straight duct. The center piece can be moved utilizing an electric motor. The throttle (annulus) area that is available during center piece motion is shown in Fig. A.1.8. It is possible to set the throttle to within a tenth of an inch (about 2.0 mms) during horizontal traverse of the throttle centerpiece. At a given Test Compressor speed, a chosen throttle setting may yield one of two types of performance: (i) when it is unchoked, the pressure ratio across the throttle (the downstream pressure being related to the atmospheric pressure) determines the mass flow throughout the Test Compressor; and (ii) when the throttle area is too large for passing the mass flow through the Test Compressor with a particular set of inlet conditions, the Compressor will operate under free-wheeling conditions.

The Test Compressor assembly with the gear box connecting it to the Drive Engine is such that there is no simple access to its outlet section for locating adequate instrumentation or adjusting probes to establish compressor outlet conditions. The gear box disassembly and removal of the compressor outlet ducting are required each time any access is desired to the compressor outlet section.

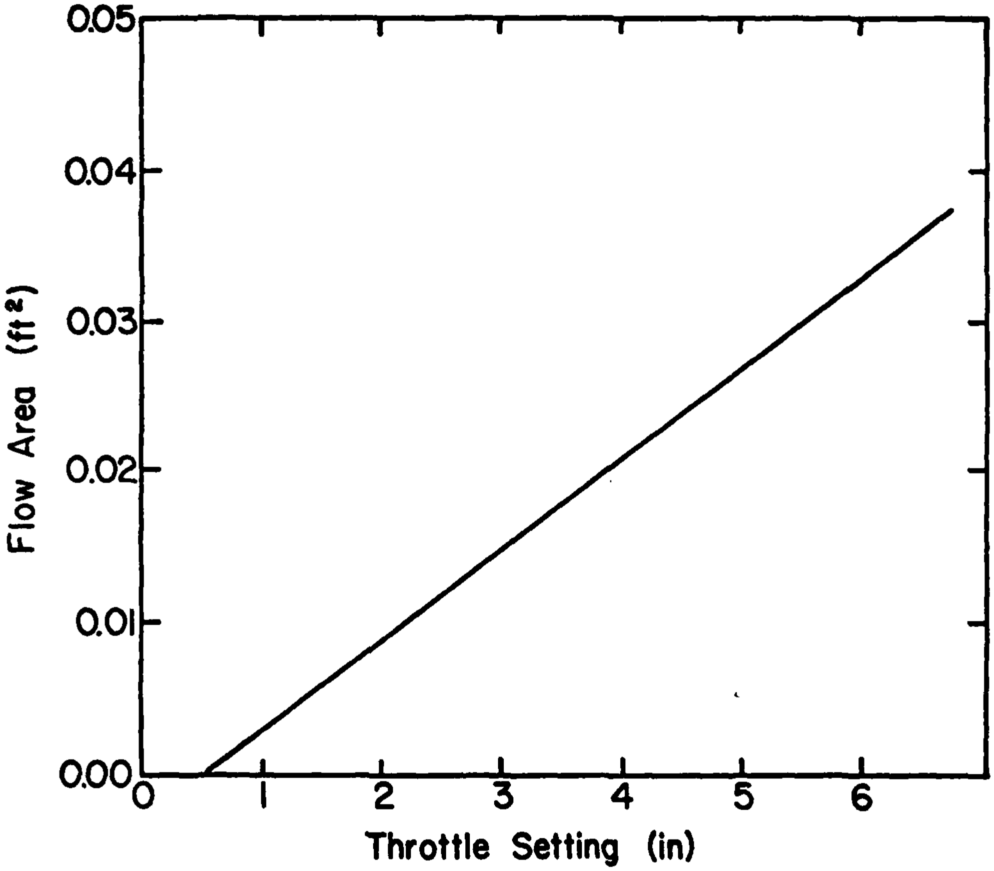

Fig. A.1.8 Flow Area vs. Throttle Setting

3.1 Refurbishment

The Drive Engine and the Test Compressor have been refurbished in the following respects by the Detroit Diesel Allison of Indianapolis, who are the original manufacturers of both the units.

(1) Engine fuel flow control;

(2) Drive shaft interconnecting the Drive Engine and the Test Compressor;

(3) Test Compressor gear box;

(4) Test Compressor bearings; and

(5) The 6-stage assembly of Test Compressor, including balancing.

Following this refurbishment and additional work undertaken at Purdue University, proof-runs undertaken on the Drive Engine - Test Compressors installation showed feasibility of satisfactory operation of the test unit.

APPENDIX 2

STAGE PERFORMANCE CALCULATION

There are two options in the PURDU-WICSTK Code for the calculation of stage performance:

(1) based on given stage characteristics, and

(2) through the estimation of work done and losses in a stage, based on an analytical model.

In both cases, several approximations are required. It may also be recalled that the stage performance calculation being discussed here pertains only to establishing the stage work done, and the consequent temperature and pressure rise, and the stage losses as they occur between the leading and trailing edges of a blade. As stated in Chapter II, and also in Reference 22, the final exit conditions from a stage are established after correcting the stage outlet conditions for various two phase flow effects.

In calculating the stage performance, it is necessary to take into account the presence of droplets in the fluid, and their motion, particularly their impact on the blades. Such impaction leads to the formation of a film on the blade surface, composed of water from unrebound droplets, and a change in the boundary layer and separation characteristics. Thus, the stage characteristics become different for a droplet-laden gas flow from those for a single phase gas. The change in stage characteristics arises through modification of (a) momentum thickness of boundary layer, (b) diffusion factor and (c) deviation angle.

It may be stated at the outset that no correlations of compressor, cascade or even single airfoil performance data are available for two phase flow. It is therefore necessary to model compressor flow based on a number of approximations, in turn related to physical process models.

In order to account for various drop sizes that may arise in a spray, it has been suggested, in Reference 22 and again in Chapter 11, that two classes of droplets be identified, one referred to as "small"and the other as "large." In adjusting droplet sizes for any reason, it is assumed that small droplets may only remain small, while large droplets may become small enough to belong to the small droplet class. From the point of view of blade passage flow, the principal distinction between small and large droplets is, as has been mentioned earlier, that small droplets are sufficiently small and follow the gas phase streamlines; but large droplets, which are in order of about 100 μm in diameter, are assumed to have equal probability of motion in all directions in the forward sector. In addition, it is assumed that only small droplets may absorb part of the work input. Other distinctions between the two classes of droplets arise from the foregoing and are taken into account in developing compressor flow models for the two classes of droplets.

In order to simplify calculations of stage losses, three procedures have been developed as follows:

(1) procedure when the compressor operate with a single (gas) phase;

(2) procedure when only small droplets are present; and

(3) procedure when large droplets are present either by themselves or along with small droplets.

Typical velocity diagram for an axial compressor stage is presented in Fig.A.2.1.

A.2.1. Procedure of Gas Phase Operation

One can use either (1) available stage characteristics or (2) an analytical/correlation method for obtaining stage characteristics. For the Test Compressor employed in this investigation, the analytical/ correlation method recommended is based on References 23 and 24.

A.2.1.1. Use of Available Stage Characteristics

The stage performance calculation for gas phase operation, with use of available stage characteristics, are carried out as follows:

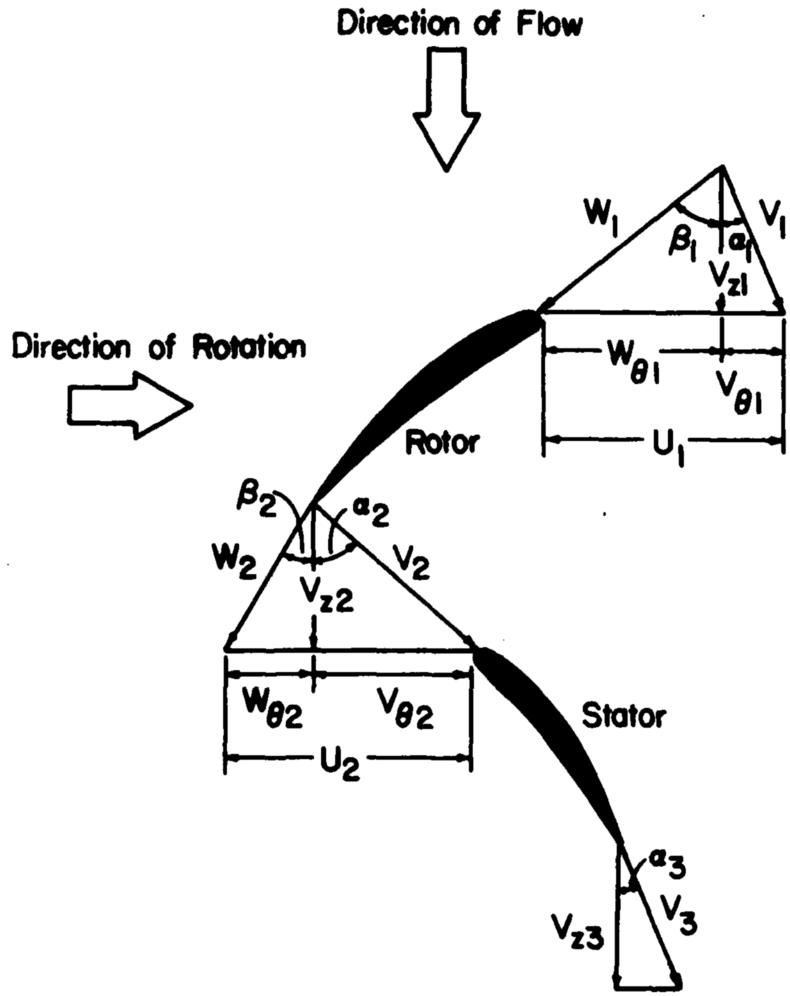

Fig. A.2.1 Typical Velocity Diagram for a Compressor Stage

(1) From given inlet conditions or the previous stage outlet conditions, the total temperature, T_{01} , and the total pressure, P_{01} , are known.

(2) Calculate the density based on T_{01} and P_{01}

$$\rho_{01} = P_{01}/R_m T_{01}$$

(3) Assume Mach number M_a.

(4) Calculate static temperature, T, and density, ρ .

$$\rho = \left\{1 + (\gamma - 1)M_a^2/2\right\}^{-1/(\gamma - 1)} \cdot \rho_{01}$$

$$T = \left\{1 + (\gamma - 1)M_a^2/2\right\}^{-1} \cdot T_{01}$$

(5) Calculate acoustic speed

$$a = (\gamma R_m T g_c)^{1/2}$$

(6) Calculate the axial velocity

$$V_z = \dot{m}_m/\rho A$$

(7) Calculate the absolute velocity at rotor inlet, V_1.

$$V_1 = V_z/\cos \alpha_1$$

(8) Calculate Mach number

$$M = V_1/a = M_c$$

(9) Compare the assumed Mach number, M_a, with the calculated one, M_c. If M_c agrees within prescribed limits with M_a, proceed to the next step. Otherwise, steps 3 to 9 should be repeated until a satisfactory accuracy is obtained.

(10) Calculate the flow coefficient, ϕ, at the entrance to the stage under consideration.

$$\phi = V_z/U_{tip}$$

(11) Enter the stage characteristics curve at the value of ϕ and obtain the equivalent pressure ratio, ψ, equivalent temperature ratio, τ, and stage adiabatic efficiency, η.

The definitions of ψ, τ, and η are as follows:

(i) flow coefficient: ϕ

$$\phi = V_z/U_{tip}$$

(ii) equivalent pressure ratio:

$$\psi = \left\{ \left(\frac{U^2_{tip}}{T_{01}}\right)_D \left(\frac{T_{01}}{U^2_{tip}}\right) \left[\left(\frac{P_{02}}{P_{01}}\right)^{(\gamma-1)/\gamma} - 1\right] + 1\right\}^{\gamma/(\gamma-1)}$$

(iii) equivalent temperature ratio: τ

$$\tau = \left(\frac{U^2_{tip}}{T_{01}}\right)_D \cdot \left(\frac{\Delta T_0}{U^2_{tip}}\right)$$

(iv) stage adiabatic efficiency:

$$\eta = T_{01}\left[\left(\frac{P_{02}}{P_{01}}\right)^{(\gamma-1)/\gamma} - 1\right] \frac{1}{\Delta T_0} = (\psi^{(\gamma-1)/\gamma} - 1)/\tau$$

where ΔT_0 is stage total temperature rise, P_0 total pressure, T_0 total temperature, V_z axial velocity, U_{tip} blade tip wheel speed, γ specific heat ratio. The subscripts 1 and 2 mean inlet and outlet, respectively, and D design value.

The equivalent pressure ratio, ψ, equivalent temperature ratio, τ, and stage adiabatic efficiency, η, may be expressed in terms of flow coefficient as follows:

$$\psi = A_1 + B_1\phi + C_1\phi^2 + D_1\phi^3 + E_1\phi^4 + F_1\phi^5 + G_1\phi^6$$
$$\eta = A_2 + B_2\phi + C_2\phi^2 + D_2\phi^3 + E_2\phi^4 + F_2\phi^5 + G_2\phi^6$$
$$\tau = A_3\phi + B_3$$

(12) Once the values of ψ, τ, and η corresponding to ϕ are obtained, the stage outlet properties can be calculated from their definitions. Actually two of them are enough to determine the stage outlet properties. In the present calculation scheme, the equivalent temperature rise ratio, τ , and the stage adiabatic efficiency, η , are used. The stage total temperature rise, ΔT_0 , stage and total temperature ratio, $T_{0\,2}/T_{0\,1}$, and stage total pressure ratio, $P_{0\,2}/P_{0\,1}$, are given by the following:

$$\Delta T_0 = \tau U_{tip}^2 / (U_{tip}/T_{0\,1})_D$$

$$T_{0\,2}/T_{0\,1} = 1 + \Delta T_0 / T_{0\,1}$$

$$P_{0\,2}/P_{0\,1} = (1 + \eta\ \Delta T_0 / T_{0\,1})^{\gamma/(\gamma-1)}$$

A.2.1.2. <u>Use of Analytical/Correlation Method</u>

The stage performance calculation for gas phase operation is carried out using the analytical/correlation method as follows:

(1) From given inlet conditions or the previous stage exit conditions, the total temperature, $T_{0\,1}$, and total pressure, $P_{0\,1}$, are obtained.

(2) Calculate specific heat ratio corresponding to the temperature.

(3) Calculate the stagnation density

$$\rho_{0\,1} = P_{0\,1}/RT_{0\,1}$$

(4) Assume a value for Mach number, M_a.

(5) Calculate the static density and temperature.

$$\rho_1 = \left\{1 + (\gamma-1)M_a^2/2\right\}^{-1/(\gamma-1)} \cdot \rho_{0\,1}$$

$$T_1 = \left\{1 + (\gamma-1)M_a^2/2\right\}^{-1} \cdot T_{0\,1}$$

(6) Calculate the acoustic speed

$$a_1 = (\gamma R T_1 g_c)^{0.5}$$

(7) Calculate the axial velocity

$$V_{z1} = \dot{m}/\rho_1 A_1$$

(8) Calculate the absolute velocity

$$V_1 = V_{z1}/\cos \alpha_1$$

(9) Calculate the Mach number, M_c.

$$M_c = V_{z1}/a_1$$

(10) Compare the assumed value of Mach number, M_a, with the calculated one, M_c. If M_a agrees within prescribed limits with M_c, proceed to the next step. Otherwise, steps (4) to (9) must be repeated.

(11) Calculate the components of velocity from the velocity diagram at rotor inlet as follows:

$$V_1 = V_{z1}/\cos \alpha_1$$

$$V_{\theta 1} = V_{z1} \tan \alpha_1$$

$$W_{\theta 1} = U_1 - V_{\theta 1}$$

$$W_1 = (V_{z1}^2 + W_{\theta 1}^2)^{0.5}$$

$$\beta_1 = \tan^{-1}(W_{\theta 1}/V_{z1})$$

(12) Calculate relative Mach number at rotor inlet

$$M_{r1} = W_1/a_1$$

(13) Calculate static pressure at rotor inlet

$$p_1 = (T_{01}/T_1)^{-\gamma/(\gamma-1)} \cdot P_{01}$$

(14) Calculate total pressure at rotor inlet based on the relative Mach number, M_r.

$$P_{01,r} = \left\{ 1 + (\gamma-1)M_{r1}^2/2 \right\}^{\gamma/(\gamma-1)} \cdot P_1$$

(15) Assuming V_{z2} , calculate the total pressure loss coefficient across rotor and rotor outlet flow angle.

(16) Calculate the components of velocity at rotor outlet as follows:

$$W_{\theta 2} = V_{z2} \tan \beta_2$$

$$V_{\theta 2} = U_2 - W_{\theta 2}$$

$$W_2 = (V_{z2}^2 + W_{\theta 2}^2)^{0.5}$$

$$V_2 = (V_{z2}^2 + V_{\theta 2}^2)^{0.5}$$

$$\alpha_2 = \tan^{-1} (V_{\theta 2}/V_{z2})$$

(17) Calculate the total temperature at rotor outlet.

$$T_{02} = T_{01} + (U_2 V_{\theta 2} - U_1 V_{\theta 1})/c_p g_c J$$

(18) Calculate static temperature at rotor outlet.

$$T_2 = T_{02} - V_2^2/2c_p g_c J$$

(19) Calculate acoustic speed at rotor outlet.

$$a_2 = (\gamma R T_2 g_c)^{0.5}$$

(20) Calculate absolute and relative Mach number at rotor outlet.

$$M_2 = V_2/a_2$$

$$M_{r2} = W_2/a_2$$

(21) Calculate total pressure loss factor across rotor.

$$\frac{P_{02,r}}{P_{01,r}} = \frac{P_{02,ri}}{P_{01,r}} = \bar{\omega}_R \left(1 - \frac{\rho_1}{P_{01,r}}\right)$$

where

$$\frac{P_{02,ri}}{P_{01,r}} = \left(\frac{T_{02,r}}{T_{01,r}}\right)^{\frac{\gamma}{\gamma-1}}$$

$$= \left\{1 + \frac{\gamma-1}{2} \; \frac{U_2^2}{RT_{01,r}} \left[1 - \left(\frac{r_1}{r_2}\right)\right]^2\right\}^{\frac{\gamma}{\gamma-1}}$$

(22) Calculate total pressure ratio across rotor, and total and static pressure at rotor outlet.

$$\frac{P_{02}}{P_{01}} = \left(\frac{T_{02}}{T_{01}}\right)^{\frac{\gamma}{\gamma-1}} \cdot \left(\frac{P_{02,r}}{P_{01,r}}\right) \cdot \left(\frac{P_{02,ri}}{P_{01,r}}\right)^{-1}$$

$$P_{02} = \left(\frac{P_{02}}{P_{01}}\right) P_{01}$$

$$P_2 = \left(1 + \frac{\gamma-1}{2} M_2^2\right)^{-\gamma/(\gamma-1)} \cdot P_{02}$$

(23) Calculate density at rotor outlet.

$$\rho_2 = P_2/RT_2$$

(24) Calculate the axial velocity at rotor outlet.

$$V_{z2} = \dot{m}/\rho_2 A_2$$

(25) Compare the calculated value of V_{z2} in (24) with the assumed V_{z2} in (15). Iterate steps (15) to (24) until a desired accuracy is obtained.

(26) Calculate total pressure at rotor outlet.

$$P_{02} = \left\{ 1 + (\gamma - 1)M_2^2/2 \right\}^{\gamma/(\gamma-1)} \cdot p_2$$

(27) Calculate the total pressure loss coefficient across stator, $\bar{\omega}_S$, and stator outlet angle α_3.

(28) Calculate total pressure loss factor across stator.

$$\frac{P_{03}}{P_{02}} = 1 - \bar{\omega}_S \left(1 - \frac{p_2}{P_{02}}\right)$$

(29) Calculate the total pressure ratio and total temperature ratio across the stage.

$$PR = \frac{P_{03}}{P_{01}} = \left(\frac{T_{03}}{T_{01}}\right)^{\frac{\gamma}{\gamma-1}} \cdot \left(\frac{P_{02,r}}{P_{01,r}}\right) \cdot \left(\frac{P_{02,ri}}{P_{01,r}}\right)^{-1} \cdot \left(\frac{P_{03}}{P_{02}}\right)$$

$$TR = T_{03}/T_{01}$$

(30) Obtain total pressure and temperature at stator outlet.

$$P_{03} = \left(\frac{P_{03}}{P_{02}}\right) \cdot P_{02}$$

$$T_{03} = T_{02}$$

(31) Calculate the average value of specific heat ratio.

(32) Calculate the stage efficiency.

$$\eta = \frac{PR^{(\gamma-1)/\gamma} - 1}{TR - 1}$$

A.2.2 <u>Procedure when Small Droplets are Present</u>.

When all of the droplets present at entry to a stage can be categorized as small droplets, the following assumptions are introduced.

(1) Droplets follow gas phase streamlines.

(2) A fraction of the droplets impacting the blades undergo rebound. The balance of impacting droplets move over the blade surface in the form of a thin film. The momentum of the thin film is negligible.

(3) The development of the boundary layer over the blade surface can be based on Reference 25. The following assumptions are made in that Reference: (i) droplets do not interact with one another; (ii) a two phase boundary layer exists; and (iii) the momentum thickness for the two phases can be superposed after they are obtained in two parts.

(4) The deviation angle remains the same in two phase flow as in single phase flow. The reasoning is that diffusion and transport of particles can be neglected as being small and, in any case, as balancing each other.

(5) The loss coefficient for two phase flow is thus the sum of the loss coefficient for each phase. The loss coefficient for the liquid phase may also be added in an appropriate form to the stage efficiency for a stage obtained during operation with air in order to obtain the stage efficiency for two phase flow.

(6) Considering a blade passage flow, between two neighboring blades, away from solid boundaries, the drag due to droplets can be calculated assuming Stokes drag relation. The number of droplets suffering such drag is the sum of the number of non-impacting droplets and the number of rebound droplets.

(7) The overall loss is obtained by adding the losses described under (5) and (6).

A.2.2.1 Use of Available Stage Characteristics

In dealing with a mixture containing small droplets, it is assumed that (a) gas phase and the small droplets behave in the same fashion in absorbing work input as a gas, and (b) the influence of small droplets arises in the determination of (a) the flow coefficient and (b) the stage losses.

In using gas flow stage characteristics for a mixture with small droplets, the pressure rise for the gas phase, the temperature rise of water and efficiency are determined for the relevant value of flow coefficient from the gas phase characteristics, and then, the efficiency is further modified to account for the presence of small droplets.

The stage performance calculation for a mixture with small droplets can thus be carried out using the available stage characteristics as follows:

(1) From the previous stage outlet properties, the gas phase total temperature, $T_{01,g}$, and the total pressure, P_{01}, are known.

(2) Calculate the gas constant, specific heat at constant pressure, and specific heat ratio of the gas phase.

(3) Calculate the stagnation density of gas phase.

(4) Assume a value for Mach number, M_a.

(5) Calculate the static density and static temperature of the gas phase.

(6) Calculate the acoustic speed in the gas phase.

(7) Calculate the acoustic speed in the mixture, a.

(8) Calculate the density of the mixture.

$$\rho_m = \left(\frac{x_g}{\rho_g} + \frac{x_w}{\rho_w}\right)^{-1}$$

(9) Calculate the axial velocity.

$$V_z = \dot{m}_m/\rho_m A$$

(10) Calculate the absolute velocity.

$$V_1 = V_z/\cos\alpha_1$$

where α_1= air outlet angle of the previous stage stator.

(11) Calculate the Mach number, M_c.

$$M_c = V_1/a$$

(12) Compare the assumed Mach number, M_a, with the calculated one, M_c. If M_a agrees reasonably well with M_c, proceed to the next step. Otherwise, steps (4) to (11) must be repeated.

(13) Calculate the flow coefficient at the entrance of the stage

$$\phi = V_z/U_{tip}$$

(14) Enter the stage characteristic curve at the foregoing value of ϕ.

The compressor stage characteristics, described in A.2.1.1., which apply to air flow through the compressor, have been utilized in this calculation for obtaining the stage temperature ratio and stage adiabatic efficiency for the mixture of air and small droplets. It may be recalled that the stage temperature rise corresponding to a mixture flow coefficient has to be apportioned between the gas and the liquid phases. The gas phase then undergoes a change in temperature and pressure while the liquid phase undergoes only a temperature change.

Utilizing the stage temperature ratio and adiabatic efficiency, one can then calculate the stage pressure ratio and the change in water temperature. In the current method of calculating stage performance for two phase flow, all of the other effects due to the presence of droplets are taken into account at the exit of the stage under consideration.

(15) Apportion energy input into the mixture.
Regarding apportionment of energy input into the mixture in a stage, one proceeds as follows. The work input is expressed by the following relations:

$$\Delta H_0 = (\Delta H_0)_1 + (\Delta H_0)_2 + (\Delta H_0)_3 + (\Delta H_0)_4$$

where

ΔH_0 : actual work input in rotor;

$(\Delta H_0)_1$: work input to gas phase;

$(\Delta H_0)_2$: work input absorbed by droplets which do not impinge upon blade surface;

$(\Delta H_0)_3$: work input absorbed by water droplets which impinge upon blade surface, adhere to form a film and are re-entrained from the trailing edge; and

$(\Delta H_0)_4$: work input absorbed by droplets which impinge upon blade surface and rebound.

Defining mass fractions as follows:

x_g : mass fraction of gas phase.

x_{w_1} : mass fraction of water which does not impinge upon blade surface

x_{w_2} : mass fraction water which impinges on the blade surface and rebounds

x_{w_3} : mass fraction of water which is re-entrained from the trailing edge.

and noting that

$$x_g + x_{w1} + x_{w2} + x_{w3} = 1,$$

one can express the work input fractions as follows in terms of the stage work done factor, λ .

$$(\Delta H_0)_1 = \lambda U_2(W_{\theta 1} - W_{\theta 2})\, x_g$$

$$(\Delta H_0)_2 = \lambda U_2(W'_{\theta 1} - W'_{\theta 2})\, x_{w1}$$

where $W_{\theta 1}$ and $W'_{\theta 1}$ are relative inlet whirl velocities of the gas phase and water droplets which do not impinge upon the blade surface, respectively, and $W'_{\theta 2}$ and $W_{\theta 2}$ are the same velocities at outlet.

Also, from physical considerations, the angular momentum change of water which impinges on the surface and adheres to form films and is finally re-entrained from the trailing edge can be considered to be negligible. Therefore,

$$(\Delta H_0)_3 = 0$$

Then, $(\Delta H_0)_4$ can be calculated by writing

$$(\Delta H_0)_4 = \Delta H_0 - (\Delta H_0)_1 - (\Delta H_0)_2$$

The total work input, ΔH_0, is calculated from the stage performance curves. In the present analysis, since we are considering small droplets, the velocity lag between gas phase and water droplet can be considered to be negligible. Accordingly $W'_{\theta 1}$ and $W'_{\theta 2}$ can be set to be the same as as $W_{\theta 1}$ and $W_{\theta 2}$.

From $(\Delta H_0)_1$, $(\Delta H_0)_2$, $(\Delta H_0)_3$, and $(\Delta H_0)_4$, the total temperature rise can be calculated for each phase.

(16) Obtain the total pressure loss because of the increase in momentum thickness of the boundary layer due to the existence of small droplets in the boundary layer.

(17) Obtain the total pressure loss due to the Stokesian drag of water droplets outside boundary layer.

(18) Calculate the stage outlet total pressure as follows:

$$P_{02} = P_{01} - \Delta P_\theta - \Delta P_S$$

where P_{02} is the stage outlet total pressure obtained from the available stage characteristics, ΔP_θ is the the total pressure loss due to the increase in momentum thickness because of the existence of small droplets in the boundary layer, and ΔP_S is the total pressure loss due to the Stokesian drag of water droplets in the free stream outside the boundary layer.

It may be pointed out that in view of the assumption pertaining to motion of small droplets (with zero relative velocity with respect to gas phase), the correction to stage pressure rise due to Stokesian drag becomes zero for small droplets.

(19) Calculate the stage total pressure ratio.

A.2.2.2 Use of Analytical/Correlation Method

In using the analytical/correlation method for the flow of a mixture with small droplets, the basic procedure is the same as when utilizing available stage characteristics, Appendix Section A.2.2. The pressure rise for the gas phase and the termperature rise of water are determined from the mixture turning angle over a blade. The losses are established based on (a) the relation (due to Lieblein) between the loss coefficient and the pressure loss; the loss coefficient in turn related to the momentum thicknesses of the blade boundary layer due to the gas phase and the droplets; and (b) the Stokesian drag of droplets in the free stream. The latter, of course, is zero for small droplets, by definition.

The stage performance calculation for a mixture with small droplets is carried out using the analytical/correlation method as follows:

(1) From the given inlet condition or the previous stage properties, the gas phase total temperature, $T_{01,g}$, and total pressure, P_{01}, are obtained.

(2) Calculate the gas constant, R_g, specific heat constant pressure, c_{pg} and specific heat ratio of gas phase, γ .

(3) Calculate the stagnation density of gas phase.

$$\rho_{01,g} = P_{01}/R_g T_{01,g}$$

(4) Assume a value for Mach number, M_a.

(5) Calculate the static density and temperature of gas phase.

$$\rho_{g_1} = \left[1 + (\gamma - 1)M_{a_2}^2/2\right]^{-1/(\gamma - 1)} . \rho_{01,g}$$

$$T_{g_1} = \left[1 + (\gamma - 1)M_a^2/2\right] . T_{01,g}$$

(6) Calculate the acoustic speed in the gas phase a_{g_1}.

$$a_{g_1} = (\gamma R_g T_{g_1} g_c)^{0.5}$$

(7) Calculate the acoustic speed in the mixture, a_1 .

(8) Calculate the density of the mixture

$$\rho_m = \left(\frac{x_g}{\rho_g} + \frac{x_w}{\rho_w} \right)^{-1}$$

(9) Calculate the axial velocity

$$V_{z_1} = \dot{m}_m/\rho_1 A_1$$

(10) Calculate the absolute velocity

$$V_1 = V_{z_1}/\cos\alpha_1$$

(11) Calculate the Mach number, M_c.

$$M_c = V_1/a_1$$

(12) Compare the assumed Mach number, M_a, with the calculated one, M_c. If M_a agrees within prescribed limits with M_c, proceed to the next step. Otherwise, steps (4) to (11) must be repeated.

(13) Calculate the components of velocity at rotor inlet as follows:

$$V_1 = V_{z_1}/\cos\alpha_1$$

$$V_{\theta_1} = V_{z_1}/\tan\alpha_1$$

$$W_{\theta_1} = U_1 - V_{\theta_1}$$

$$W_1 = (V_{z_1}^2 + W_{\theta_1}^2)^{1/2}$$

$$\beta_1 = \tan^{-1}(W_{\theta_1}/V_{z_1})$$

(14) Calculate relative Mach number at rotor inlet

$$M_{r_1} = W_1/a_1$$

(15) Calculate static pressure at rotor inlet

$$p_1 = (T_{01,g}/T_{g_1})^{-\gamma/(\gamma-1)} \cdot P_{01}$$

(16) Calculate total pressure at rotor inlet based on the relative Mach number, M_{r_1} .

$$P_{01,r} = \{1 + (\gamma - 1)M_{r_1}/2\}^{\gamma/(\gamma - 1)} \cdot p_1$$

(17) Assuming V_{z_2} the total pressure loss coefficient across rotor due to gas phase, $\overline{\omega}_{g,R}$, and rotor outlet angle β_2.

(18) Obtain the total pressure loss coefficient due to the increase of momentum thickness because of the existence of small droplets in the boundary layer over a rotor blade surface $\overline{\omega}_{\theta,R}$.

(19) Obtain the total pressure loss across rotor due to the Stokesian drag of water droplets outside boundary layer $\overline{\omega}_{s,R}$.

(20) Calculate the components of velocity at rotor outlet as follows:

$$W_{\theta_2} = V_{z2}\tan\beta_2$$

$$V_{\theta_2} = U_2 - W_{\theta 2}$$

$$W_2 = (V_{z2}^2 + W_{\theta 2}^2)^{0.5}$$

$$V_2 = (V_{z2}^2 + V_{\theta 2}^2)^{0.5}$$

$$\alpha_2 = \tan^{-1}(V_{\theta 2}/V_{z2})$$

(21) Calculate the work input.

$$\Delta H_0 = (U_2 V_{\theta 2} - U_1 V_{\theta 1})/g_c J$$

(22) Apportion work input to the mixture constituents as described in item (14) of A.2.2.1.

(23) Calculate static temperature of gas phase at rotor outlet.

$$T_{g_2} = T_{02,g} - V_2^2/c_{pg}\, g_c\, J$$

(24) Calculate acoustic speed in gas phase.

$$a_{g_2} = (\gamma\, R_g T_{g2} g_c)^{0.5}$$

(25) Assume $\rho_{g2} = \rho_{g1}$ and calculate the acoustic speed in the mixture, a_2.

(26) Calculate absolute and relative Mach numbers at rotor outlet.

$$M_2 = V_2/a_2$$

$$M_{r_2} = W_2/a_2$$

(27) Calculate total pressure loss factor across rotor.

$$\frac{P_{02,r}}{P_{01,r}} = \frac{P_{02,ri}}{P_{01,r}} - (\bar{\omega}_{g,R} + \bar{\omega}_{\theta,R} + \bar{\omega}_{s,R}) \cdot (1 - \frac{P_1}{P_{01,r}})$$

(28) Calculate total pressure ratio across rotor, and total and static pressures at rotor outlet.

$$\frac{P_{02}}{P_{01}} = \left(\frac{T_{02,g}}{T_{01,g}}\right)^{\frac{\gamma}{\gamma-1}} \cdot \left(\frac{P_{02,r}}{P_{01,r}}\right) \cdot \left(\frac{P_{02,ri}}{P_{01,r}}\right)^{-1}$$

$$P_{02} = \left(\frac{P_{02}}{P_{01}}\right) P_{01}$$

$$P_2 = (1 + \frac{\gamma - 1}{2} M_2^2)^{\frac{-\gamma}{\gamma - 1}} P_{02}$$

(29) Calculate static density at rotor outlet.

$$\rho_{g_2} = p_2/R_g T_{g2}$$

(30) Compare the calculated value of ρ_{g2} in (29) with the assumed value of ρ_{g2} in (25). Iterate steps (25) to (29) until a desired accuracy is obtained.

(31) Calculate the density of mixture at rotor outlet.

$$\rho_{m2} = \left(\frac{x_g}{\rho_{g2}} + \frac{x_w}{\rho_w}\right)^{-1}$$

(32) Calculate the axial velocity at rotor outlet.

$$V_{z_2} = \dot{m}_m/\rho_m A$$

(33) Compare the calculated value of V_{z_2} in (32) with the assumed value of V_{z_2} in (17). Iterate steps (17) to (32) until a desired accuracy is obtained.

(34) Calculate total pressure at rotor outlet.

$$P_{02} = \left\{1 + (\gamma - 1) M_2^2/2\right\}^{\gamma/(\gamma-1)} . P_2$$

(35) Calculate the total pressure loss coefficient across stator due to gas phase, $\overline{\omega}_{g,S}$, and stator outlet angle, α_3.

(36) Obtain the total pressure loss coefficient due to the increase of momentum thickness because of the existence of small droplets in the boundary layer on a stator blade surface, $\overline{\omega}_{\theta,S}$.

(37) Obtain the total pressure loss across stator due to the Stokesian drag of water droplets in the free stream outside boundary layer $\bar{\omega}_{s,S}$. It may be noted that Stokesian drag is zero in the case of small droplets by definition.

(38) Calculate total pressure loss factor across stator.

$$\frac{P_{03}}{P_{02}} = 1 - (\bar{\omega}_{g,S} + \bar{\omega}_{\theta,S} + \bar{\omega}_{s,S})\ (1 - \frac{P_2}{P_{02}})$$

(39) Calculate the total pressure ratio and gas phase total temperature ratio across stage.

$$PR = \frac{P_{03}}{P_{01}} = \left(\frac{T_{03,g}}{T_{01,g}}\right)^{\frac{\gamma}{\gamma-1}} \cdot \left(\frac{P_{02,r}}{P_{01,r}}\right)\left(\frac{P_{02,ri}}{P_{01,r}}\right)^{-1} \cdot \left(\frac{P_{03}}{P_{02}}\right)$$

$$TR = T_{03,g}/T_{01,g}$$

(40) Obtain total pressure and gas phase total temperature at stator outlet.

$$P_{03} = \left(\frac{P_{03}}{P_{02}}\right) P_{02}$$

$$T_{03,g} = T_{02,g}$$

(41) Calculate the average value of specific heat ratio.

(42) Calculate the stage efficiency.

$$\eta = \frac{PR^{(\gamma-1)/\gamma} - 1}{TR - 1}$$

A.2.3 Procedure when Large or Large and Small Droplets are Present

It is postulated that when large droplets are present, they always play the more dominant role.

The following assumptions are introduced.

(1) Droplets move with equal probability in all directions in the forward sector.

(2) A fraction of the droplets impacting the droplets undergo rebound. The balance of impacting droplets move over the blade surface in the form of a thick film. The momentum of the thick film is appreciable and represents a loss of mixture momentum.

(3) The development of the boundary layer can be estimated based on the following reasoning: (a) The thick film presents a continuous rough surface; (b) the roughness is at most of the order of droplet thickness; and (c) the boundary layer is fully turbulent and extends over the chord length. A coefficient of friction for the flow can then be based on Ref. 26.

(4) The deviation angle remains the same as in the case of single phase flow.

(5) Considering a blade passage flow, between two neighboring blades, away from solid boundaries, the drag due to droplets can be calculated assuming Stokes drag relation, The number of droplets suffering such drag is the sum of the number of non-impacting droplets and the number of rebound droplets.

(6) The overall loss is therefore obtained by adding the losses described under (2), (3) and (5).

It may be observed that the foregoing procedure for large droplets precludes the use of available stage characteristics and subsequent correction of efficiency due to the presence of droplets. The procedure is also different from the Lieblein analytical/correlation method used in the case of small droplets in that no simple superposition of blade

profile losses is feasible in the case of large droplets. The loss due to Stokesian drag of large droplets in the free stream, of course, is accounted for by simple addition to other losses.

A.2.3.1. Details of Procedure

The stage performance, when large droplets are present, with or without small droplets, is carried out as follows. It may be pointed out that the determination of stage pressure ratio follows the same procedure as in the case of a mixture with small droplets only, Appendix Section A.2.2.2. The determination of the loss coefficient when large droplets are present is wholly different.

(1) From given initial conditions or from the previous stage properties the gas phase total temperature, $T_{01,g}$ and total pressure, P_{01}, are obtained.

(2) Calculate the gas constant, R_g, specific heat at constant pressure, c_{pg}, and specific heat ratio, γ .

(3) Calculate the stagnation density of gas phase,

$$\rho_{01,g} = P_{01}/R_g T_{01,g}$$

(4) Assume a value for Mach number, M_a.

(5) Calculate the static density, and temperature of gas phase, as follows,

$$\rho_1 = \left\{ 1 + (\gamma - 1)M_{a2}^2/2 \right\}^{-1/(\gamma - 1)} . \rho_{01,g}$$

$$T_{g_1} = \left\{ 1+(\gamma - 1) M_{a_2}^2/2 \right\}^{-1} . T_{01,g}$$

(6) Calculate the acoustic speed in the gas phase, a_{g1}.

$$a_{g1} = (\gamma R_g T_{g1} g_c)^{0.5}$$

(7) Calculate the acoustic speed in the mixture, a_1.

(8) Calculate the density of the mixture.

$$\rho_m = \left(\frac{x_g}{\rho_g} + \frac{x_w}{\rho_w}\right)^{-1}$$

(9) Calculate the axial velocity.

$$V_{z1} = \dot{m}_m/\rho_m A$$

(10) Calculate the absolute velocity.

$$V_1 = V_{z1}/\cos \alpha_1$$

(11) Calculate the Mach number, M_c.

$$M_c = V_1/a_1$$

(12) Compare the assumed Mach number, M_a, with the calculated one, M_c. If M_a agrees within prescribed limits with M_c, proceed to the next step. Otherwise steps (4) to (11) must be repeated.

(13) Calculate the components of velocity at rotor inlet as follows:

$$V_1 = V_{z1}/\cos\alpha_1$$

$$V_{\theta 1} = V_{z1}\tan\alpha_1$$

$$W_{\theta 1} = U_1 - V_{\theta 1}$$

$$W_1 = (V_{z1}^2 + W_{\theta 1}^2)^{1/2}$$

$$\beta_1 = \tan^{-1}(W_{\theta 1}/V_{z1})$$

(14) Calculate relative Mach number at rotor inlet.

$$M_{r_1} = W_1/a_1$$

(15) Calculate static pressure at rotor inlet.

$$p_1 = \left\{ (T_{01,g}/T_g) \right\}^{-\gamma/(\gamma-1)} \cdot P_{01}$$

(16) Calculate total pressure at rotor inlet based on M_r.

$$P_{01,r} = \left\{ 1 + (\gamma - 1) M_{r_1}/2 \right\}^{\gamma/(\gamma-1)} \cdot P_1$$

(17) Assuming V_{z_2}, calculate the total pressure loss due to gas phase, $\bar{\omega}_{g,R}$, and rotor outlet angle β_2

(18) Calculate the total pressure loss coefficient due to the momentum gained by thick water film moving over the rotor blade surface, $\bar{\omega}_{f,R}$.

(19) Calculate the total pressure loss coefficient due to turbulent flow of mixture over the rough film surface of rotor blade , $\bar{\omega}_{r,R}$.

(20) Calculate the total pressure loss coefficient due to the Stokesian drag of water droplets in rotor passage, $\bar{\omega}_{s,R}$.

(21) Calculate the components of velocity diagram at rotor outlets as follows:

$$W_{\theta 2} = V_{z2} \tan \beta_2$$

$$V_{\theta 2} = U_2 - W_{\theta 2}$$

$$W_2 = (V_{z2}^2 + W_{\theta 2}^2)^{0.5}$$

$$V_2 = (V_{z2}^2 + V_{\theta 2}^2)^{0.5}$$

$$\alpha_2 = \tan^{-1}(V_{\theta 2}/V_{z2})$$

(22) Calculate the work input.

$$\Delta H_0 = (U_2 V_{\theta 2} - U_1 V_{\theta 1})/g_c J$$

(23) Apportion the energy input in the mixture as described in item (15) of A.2.2.1.

(24) Calculate static temperature of gas phase at rotor outlet.

$$T_{g2} = T_{02,g} - V_2^2/2c_{pg} g_c J$$

(25) Calculate the acoustic speed in gas phase.

$$a_{g_2} = (\gamma R_g T_{g2} g_c)^{0.5}$$

(26) Assume $\rho_{g_2} = \rho_{g_1}$ and calculate the acoustic speed in the mixture a_2.

(27) Calculate absolute and relative Mach number at rotor outlet.

$$M_2 = V_2/a_2$$

$$M_{r_2} = W_2/a_2$$

(28) Calculate total pressure loss factor across rotor.

$$\frac{P_{02,r}}{P_{01,r}} = \frac{P_{02,ri}}{P_{01,r}} - (\bar{\omega}_{g,R} + \bar{\omega}_{f,R} + \bar{\omega}_{r,R} + \bar{\omega}_{s,R}) \cdot (1 - \frac{p_1}{P_{01,r}})$$

(29) Calculate total pressure ratio across rotor, and total static pressure at rotor outlet.

$$\frac{P_{02}}{P_{01}} = (\frac{T_{02,g}}{T_{01,g}})^{\frac{\gamma}{\gamma-1}} \cdot (\frac{P_{02,r}}{P_{01,r}}) \cdot (\frac{P_{02,ri}}{P_{01,r}})^{-1}$$

$$P_{02} = (\frac{P_{02}}{P_{01}}) P_{01}$$

$$p_2 = (1 + \frac{\gamma - 1}{2} M_2^2)^{\frac{-\gamma}{\gamma-1}} P_{02}$$

(30) Calculate static density at rotor outlet.

$$\rho_{g_2} = p_2/R_g T_{g2}$$

(31) Compare the calculated ρ_{g_2} in (27) with the assumed ρ_{g2} in (23). Iterate steps (23) to (27) until a desired accuracy is obtained.

(32) Calculate the density of mixture.

$$\rho_{m_2} = \left(\frac{x_g}{g} + \frac{x_w}{w} \right)^{-1}$$

(33) Calculate the axial velocity at rotor outlet.

$$V_{z_2} = \dot{m}_m/\rho_m A_2$$

(34) Compare the calculated V_{z_2} in (33) with the assumed V_{z_2} in (34). Iterate steps (17) to (33) until the desired accuracy is obtained.

(35) Calculate total pressure at rotor outlet.

$$P_{02} = \left\{ 1 + (\gamma - 1) M_2^2/2 \right\}^{\gamma/(\gamma-1)} \cdot p_2$$

(36) Calculate the total pressure loss coefficient across stator due to gas phase, $\bar{\omega}_{g,S}$, and stator outlet angle, α_3.

(37) Calculate the the total pressure loss coefficient due to the momentum gained by thick water film on the stator blade surface, $\bar{\omega}_{f,S}$.

(38) Calculate the total pressure loss coefficient due to turbulent friction over a rough film surface over the stator blade, $\bar{\omega}_{r,S}$.

(39) *Obtain the total pressure loss across stator due to Stokesian* drag of large water droplets in the free stream outside boundary layer, $\bar{\omega}_{s,S}$.

(40) Calculate total pressure loss factor across the stator.

$$\frac{P_{03}}{P_{02}} = 1 - (\bar{\omega}_{g,S} + \bar{\omega}_{f,S} + \bar{\omega}_{r,S} + \bar{\omega}_{s,S}) \left(1 - \frac{P_2}{P_{02}}\right)$$

(41) Calculate the total pressure ratio and gas phase total temperature ratio across stage.

$$PR = P_{03}/P_{01} = \left(\frac{T_{03,g}}{T_{01,g}}\right)^{\frac{\gamma}{\gamma-1}} \cdot \left(\frac{P_{02,g}}{P_{01,r}}\right) \cdot \left(\frac{P_{02,ri}}{P_{01,r}}\right)^{-1} \cdot \left(\frac{P_{03}}{P_{02}}\right)$$

$$TR = T_{03,g}/T_{01,g}$$

(42) Obtain total pressure and gas phase total temperature at stator outlet.

$$P_{03} = \left(\frac{P_{03}}{P_{02}}\right) \cdot P_{02}$$

$$T_{03,g} = T_{02,g}$$

(43) Calculate the average value of the specific heat ratio.

(44) Calculate the stage efficiency.

$$\eta = \frac{PR^{(\gamma-1)/\gamma} - 1}{TR - 1}$$

APPENDIX 3

DETAILED DESCRIPTION OF SUBROUTINES AND EXTERNAL FUNCTIONS

There are 27 subroutines and 13 external functions in this program. Brief descriptions of these subprograms are presented in Chapter III. A more detailed description of each subprograms is presented here. Each of the subroutines and external functions is presented as follows: (1) Description, (2) Input variables, (3) Output variables, and (4) Usage.

SUBROUTINE WICSPA

(1) Description:

The subroutine WICSPA is used for the calculation of performance based on the inputed stage characteristic curves. A detailed descriptions of calculation procedure is presented in Appendix 2.

(2) Input Variables:

FAIO	initial flow coefficient
ISTAGE	stage at which performance calculation is carried out
MMASS	mass flow rate of mixture.
ALFA1	absolute flow angle at outlet of the previous stage stator
WKDONE	work done factor
DAVE	nominal diameter of small droplet
XDIN	initial water content of small droplet
AK1	constant in Eq. (A.3.6)'
AK3	constant in Eqs. (A.3.1)' and (A.3.2)'

(3) Output Variables:

ETA	stage adiabatic efficiency
BETA1	relative flow angle at rotor inlet
BETA2	relative flow angle at rotor outlet
VZ	axial velocity

ALFA2	absolute flow angle at stator inlet
ALFA3	absolute flow angle at stator outlet
DELTG	rise in total temperature of gas phase across a stage
DELTW	rise in temperature of small droplet across a stage
W1	relative velocity at rotor inlet
W2	relative velocity at rotor outlet
V1	absolute velocity at rotor inlet
V2	absolute velocity at stator inlet
V3	absolute velocity at stator outlet

(4) Usage:

```
CALL WICSPA (FAIO, ISTAGE, MMASS, ALFA1 ,WKDONE, DAVE,XDIN
           ETA, BETA1,BETA2, VZ, ALFA2, ALFA3, DELTG,DELTW
           W1,W2, V1,V2,V3, AK1, AK3)
```

<u>SUBROUTINE WICSPB</u>

(1) Description:

The subroutine WICSPB is used for the calculation of stage performance based on the analytical/correlation method for small droplet. A detailed description of calcualtion procedure is presented in Appendix 2.

(2) Input Variables:

FAIO	initial flow coefficient
ISTAGE	stage at which performance calculation is carried out
MMASS	mass flow rate of mixture
ALFA1	absolute flow angle at outlet of the previous stage stator
WKDONE	work done factor
DAV	nominal diameter of small droplets

DELV	relative velocity between gas phase and large droplets
XMAS	mass flow rate of small droplets
N	station number (Fig. 5.1)
AK1	constant in Eq. (A.3.6)'
AK2	constant in Eq. (A.3.7)' and (A.3.8)'
AK3	constatn in Eq. (A.3.1)' and (A.3.2)'

(3) Output Variables:

OMEGA1	total pressure loss coefficient due to single-phase (gas) flow profile loss in rotor
OMEGA2	total pressure loss coefficient due to loss for small droplets on account of the change in momentum thickness of boundary layer due to the presence of such droplets in rotor
OMEGA3	total pressure loss coefficient due to Stokesian drag of small droplets in the free stream of blade passage in rotor
OMEGA4	total pressure loss coefficient due to single-phase (gas) flow profile loss in stator
OMEGA5	total pressure loss coefficient due to loss for small droplets on account of the change in momentum thickness of boundary layer due to the presence of such droplets in stator
OMEGA6	total pressure loss coefficient due to Stokesian drag of small droplets in the free stream of blade passage in stator
OMEGAT	sum of total pressure loss coefficients

BETA1	relative flow angle at rotor inlet
BETA2	relative flow angle at rotor outlet
VZ	axial velocity
ALFA2	absolute flow angle at stator inlet
ALFA3	absolute flow angle at stator outlet
DELTG	rise in total temperature of gas phase across a stage
DELTW	rise in temperature of small droplet across a stage
W1	relative velocity at rotor inlet
W2	relative velocity at rotor outlet
V1	absolute velocity at rotor inlet
V2	absolute velocity at stator inlet
V3	absolute velocity at stator outlet

(4) Usage:

```
CALL WICSPB (FAIO, ISTAGE, MMASS, ALFA1, WKDONE, DAV,
            DELV, WMAS, N, OMEGA1, OMEGA2, OMEGA3,
            OMEGA4, OMEGA5, OMEGA6, OMEGAT, BETA1,
            BETA2, VZ,ALFA2, ALFA3, DELTG, DELTW, W1,
            W2, V1, V2, V3, AK1, AK2, AK3)
```

SUBROUTINE WICSPC

(1) Description:

The subroutine WICSPC is used for the calculation of stage performance based on the analytical/correlation method for large droplet. A detailed description of calculation procedure is presented in Appendix 2.

(2) Input Variables:

FAIO	initial flow coefficient
ISTAGE	stage at which performance calculation is carried out
MMASS	mass flow rate of mixture
ALFA1	absolute flow angle at outlet of the previous stage stator
WKDONE	work done factor
DAV	nominal diameter of large droplets
DELV	relative velocity between gas phase and large droplets
WMAS	mass flow rate of small droplets
WWMAS	mass flow rate of large droplets
N	station number (Fig. 5.1)
REAVE	Average Reynolds number

DELVU2	relative velocity between gas phase and droplet
DELVL2	relative velocity between gas phase and droplet
AK1	constant in Eq. (A.3.6.)'
AK2	constant in Eq. (A.3.7)' and (A.3.8)'
AK3	constant in Eq. (A.3.1)' and (A.3.2)'

(3) Output Variables:

OMEGA1	total pressure loss coefficient due to the mixture boundary layer formed over rough film surface in rotor
OMEGA2	total pressure loss coefficient due to film formed on rotor blade surface
OMEGA3	total pressure loss coefficient due to Stokesian drag of large droplets in the free stream of blade passage in rotor
OMEGA4	total pressure loss coefficient due to the mixture boundary layer formed over rough film surface in stator
OMEGA5	total pressure loss coefficient due to film formed on stator blade surface
OMEGA6	total pressure loss coefficient due to Stokesian drag of large droplets in the free stream of blade passage in stator

OMEGAT	sum of total pressure loss coefficient
BETA1	relative flow angle at rotor inlet
BETA2	relative flow angle at rotor outlet
VZ	axial velocity
ALFA2	absolute flow angle at stator inlet
ALFA3	absolute flow angle at stator outlet
DELTG	rise in total temperature of gas phase across a stage
DELTW	rise in temperature of small droplet across a stage
W1	relative velocity at rotor inlet
W2	relative velocity at rotor outlet
V1	absolute velocity at rotor inlet
V2	absolute velocity at stator inlet
V3	absolute velocity at stator outlet

(4) Usage:

```
CALL WICSPC (FAIO, ISTAGE , MMASS, ALFA1, WKDONE, DAV,
            DELV, WMAS, WWMAS, N, OMEGA1, OMEGA2, OMEGA3,
            OMEGA4, OMEGA5, OMEGA6, OMEGAT, BETA1, BETA2,
            VZ, ALFA2, ALFA3, DELTG, DELTW, W1, W2, V1, V2,
            V3, REAVE, DELVU2, DELVL2, AK1, AK2, AK3)
```

SUBROUTINE WICSPD

(1) Description

The subroutine WICSPD is used for the calculation of design point performance. The properties obtained in this subroutine become reference properties for calculation of off-design performance.

(2) Input Variables

AMASS mass flow rate

ISTAGE stage at which performance calculation is carried out

(3) Output Variables:

none

(4) Usage:

CALL WICSPD (AMASS, ISTAGE)

SUBROUTINE WICSCC

(1) Description:

Subroutine WICSCC calculates the equivalent pressure ratio, stage adiabatic efficiency, and equivalent temperature ratio for a particular stage from the inputed stage characteristic curves. The equivalent pressure ratio, ψ, equivalent temperature ratio, τ, and stage adiabatic efficiency, η have been expressed in terms of the stage flow coefficient as follows:

$$\psi = A_1 + B_1\phi + C_1\phi^2 + D_1\phi^3 + E_1\phi^4 + F_1\phi^5 + G_1\phi^6$$

$$\eta = A_2 + B_2\phi + C_2\phi^2 + D_2\phi^3 + E_2\phi^4 + F_2\phi^5 + G_2\phi^6$$

$$\tau = A_3\phi + B_3$$

The definitions of these parameters are as follows:

(i) flow coefficient: ϕ

$$\phi = V_z/U_{tip}$$

(ii) equivalent pressure ratio ψ

$$\psi = \left\{\left(\frac{U_{tip}^2}{T_{01}}\right)_D \left(\frac{T_{01}}{U_{tip}^2}\right) \left[\left(\frac{P_{02}}{P_{01}}\right)^{(\gamma-1)/\gamma} - 1\right] + 1\right\}^{\gamma/(\gamma-1)}$$

(iii) equivalent temperature ratio:

$$\tau = \left(\frac{U_{tip}^2}{T_{01}}\right)_D \cdot \left(\frac{\Delta T_0}{U_{tip}^2}\right)$$

where subscript D indicates the design point.

It should be noted here that the subroutine WICSCC is only suitable for the case of Test Compressor employed in the current investigation. In another case, a replacement of this subroutine is necessary.

(2) Input Variables:

FAI	stage flow coefficient
ISTAGE	stage number

(3) Output Variables:

SAI	equivalent pressure ratio
ETA	stage adiabatic efficiency
TAU	equivalent temperature ratio

(4) Usage:

```
CALL WICSP (FAI, SAI, ETA, TAU, ISTAGE)
```

SUBROUTINE WICGSL

(1) Description:

The subroutine WICGSL is used for the calculation of single-phase (gas) flow loss. In the current model, the concept of the equivalent diffusion ratio by Lieblein (Ref.23) and Swan's correlation (Ref.24) have been employed in order to estimate the blade outlet flow angle and loss due to turbulent flow of gaseous phase over the rigid blade surface.

Lieblein has show that the design point loading factor, the Diffusion Factor, does not represent a suitable criterion for loading at off-design conditions, except possibly at

other minimum loss points. This is due to the fact that the basic derivation of the Diffusion Factor has been based on a flow model which corresponds to operation at or near minimum loss. He has therefore suggested a generalized loading parameter. This parameter, the Equivalent Diffusion Ratio, is based on the ratio of the maximum suction surface velocity and trailing edge velocity for a given section cascade. Lieblein has deduced an expression which approximates this velocity ratio in terms of measured overall performance. The Equivalent Diffusion Ratio is suitable for correlation of low speed data. For the general case where the axial velocity ratio may be large, such as in a rotor or stator cascade, the Equivalent Diffusion Ratio, D_{eq}, has been defined as follows:

$$D_{eq} = \frac{\cos\beta_2 V_{z_1}}{\cos\beta_1 V_{z_2}} \left[1.12 + k\,(i-i^*)^{1.43} + 0.61 \frac{\cos^2\beta}{\sigma} \cdot K \right] \quad \text{(A.3.1)}$$

$$\text{where } K = \tan\beta_1 - \frac{r_2}{r_1} \frac{V_{z_2}}{V_{z_1}} \cdot \tan\beta_2 - \frac{\omega r_1}{V_{z_1}} \left(1 - \frac{r_2^2}{r_1^2}\right)$$

and k = 0.0117 for the NACA 65 (A_{10}) blades and k = 0.007 for the C_4 circular-arc blades. The Equivalent Diffusion Ratio at minimum loss, $D_{eq}{}^*$, is obtained by dropping the term representing the incidence angle effects, that is as follows.

$$D_{eq}{}^* = \frac{\cos\beta_2 V_{z_1}}{\cos\beta_1 V_{z_2}} \left\{ 1.12 + 0.61 \frac{\cos^2\beta_1}{\sigma} \cdot K \right\} \quad \text{(A.3.2)}$$

The wake momentum thickness can be expressed nondimensionally as follows:

$$\frac{\theta}{c} = \frac{\bar{\omega}\cos\beta_2}{2\sigma} \left(\frac{\cos\beta_1}{\cos\beta_2} \right)^2 \quad \text{(A.3.3)}$$

where c is the chord length of the blades.

At minimum loss, Eq. (A.3.3) yields

$$\left(\frac{\theta}{c}\right) = \frac{\bar{\omega}^* \cos\beta_2}{2\sigma} \left[\frac{\cos\beta_2^*}{\cos\beta_1^*}\right] \qquad \text{(A.3.4)}$$

Also, from Eq. (A.3.3), the total pressure loss coefficient $\bar{\omega}$, can be expressed as follows:

$$\bar{\omega} = \left(\frac{\theta}{c}\right) \frac{2\sigma}{\cos\beta_2} \left[\frac{\cos\beta_1}{\cos\beta_2}\right]^2 \qquad \text{(A.3.5)}$$

From the cascade test data, the deviation angle, δ, and the non-dimensional wake momentum thickness, $\frac{\theta}{c}$, are expressed in terms of the D_{eq}, D_{eq}^*, $(\frac{\theta}{c})^*$, and inlet Mach number, M , as follows:

$$\delta = \delta^* + \left[6.40 - 9.45(M_1 - 0.60)\right] (D_{eq} - D_{eq}^*) \;.\; AK1 \qquad \text{(A.3.6)}$$

$$\frac{\theta}{c} = \left(\frac{\theta}{c}\right)^* + (0.827M_1 - 2.692M_1^2 - 2.675M_1^3)\,(D_{eq} - D_{eq}^*)^2 \;.\; AK2 \qquad \text{(A.3.7)}$$

$$\text{for } D_{eq} D_{eq}^*$$

$$\frac{\theta}{c} = \left(\frac{\theta}{c}\right)^* + (2.80M_1 - 8.71M_1^2 + 9.36M_1^3)\,(D_{eq} - D_{eq}^*)^2 \;.\; AK2 \qquad \text{(A.3.8)}$$

$$\text{for } D_{eq}\ D_{eq}^*$$

Using these empirical expressions, the air angle at blade outlet and total pressure loss coefficient at an off-design point can be determined as follows:

(i) Calculate the inlet angle, β_1 , and the inlet Mach number, M_1.

(ii) Calculate the Equivalent Diffusion ratio at minimum loss, D_{eq}^*.

(iii) Calculate the nondimensional wake momentum thickness at minimum loss, $(\frac{\theta}{c})^*$.

(iv) Assume the fluid outlet angle , $(\beta_2)_a$.

(v) Calculate the incidence angle, i, $i=\beta_1-\beta_1^*+i^*$.

(vi) Calculate the Equivalent Diffusion Ration D_{eq}.

(vii) Calculate the deviation angle, δ .

(viii) Calculate the fluid outlet angle, $(\beta_2)_c$, $(\beta_2)_c = \beta_2^* - \delta^* + \delta$.

(ix) Compare the assumed value of fluid outlet angle, $(\beta_2)_a$, with the calculated value of that, $(\beta_2)_c$ to check if $|(\beta_2)_a - (\beta_2)_c| < \varepsilon$ where ε is the desired accuracy. Iterate step (iv) to step (ix) until satisfactory accuracy is obtained.

(x) Calculate the nondimensional wake momentum thickness, $\frac{\theta}{c}$.

(xi) Calculate the total pressure loss coefficient $\overline{\omega}$.

Figure (A.3.1) shows the flow chart of the calculation procedure to predict the outlet angle and total pressure loss coefficient.

The program also includes a provision for modifying the equations given in Ref.23 and 24. Equations (A.3.1), (A.3.2), (A.3.6), (A.3.7), and (A.3.8) can be modified by introducing constants AK1, AK2, and AK3 as follows.

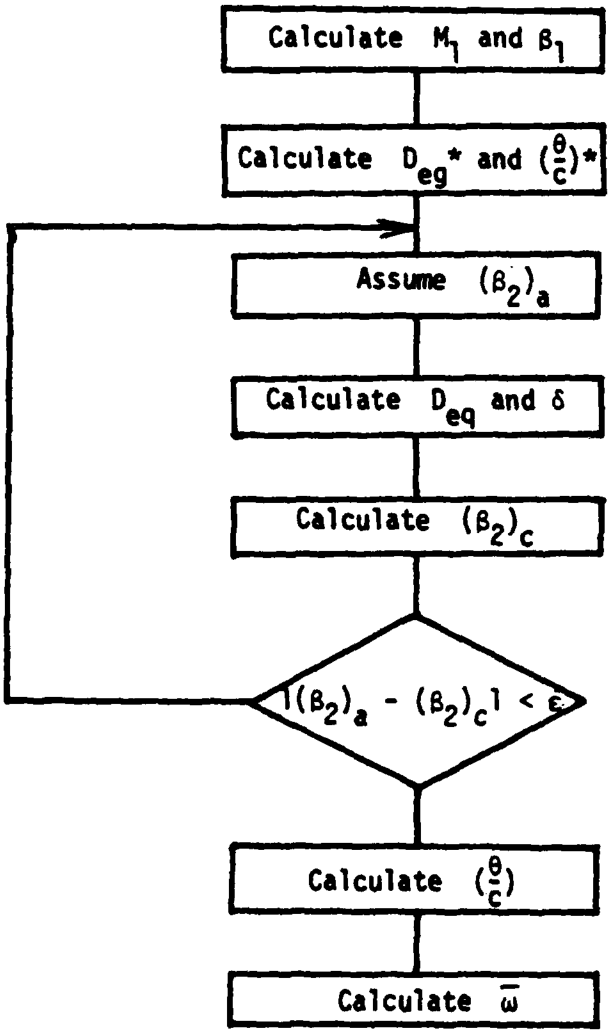

Fig. A.3.1 Procedure for Prediction of Total Pressure Loss Coefficient

$$D_{eq} = \frac{\cos\beta_2}{\cos\beta_1}\frac{V_{z1}}{V_{z2}}\left[1.12 + k\,(i-i^*)^{1.43} + 0.61\,\frac{\cos^2\beta_1}{\sigma}K\right]\cdot AK3$$

(A.3.1)'

$$D_{eq}^* = \frac{\cos\beta_2}{\cos\beta_1}\frac{V_{z1}}{V_{z2}}\left[1.12 + 0.61\frac{\cos^2\beta_1}{\sigma}\right]\cdot AK3 \quad \text{(A.3.2)'}$$

$$\delta = \delta^* + \left[6.40 - 9.45\,(M_1-0.60)\right]\,(D_{eq}-D_{eq}^*)\cdot AK1$$

(A.3.6)'

$$\frac{\theta}{c} = \left(\frac{\theta}{c}\right)^* + (0.827M_1 - 2.692M_1^2 - 2.695M_1^3)\,(D_{eq}-D_{eq}^*)^2\cdot AK2$$

for $D_{eq} > D_{eq}^*$ (A.3.7)'

$$\frac{\theta}{c} = \left(\frac{\theta}{c}\right)^* + (2.80M_1 - 8.71M_1^2 + 9.36M_1^3)\,(D_{eq}-D_{eq}^*)^2\cdot AK2$$

for $D_{eq} < D_{eq}^*$ (A.3.8)'

(2) Input Variables;

OMEGAS	total pressure loss coefficient
SIGUMA	solidity
BETA1S	blade inlet flow angle at design point
BETA2S	blade outlet flow angle at design point
AINCIS	incidence at design point
ADEVIS	deviation at design point
AMACH1	blade inlet Mach number
BET1	blade inlet flow angle

X	Mach number below which the effect of Mach number disappears in estimating deviation angle. The value of 0.6 is recommended by Swan (Ref.24).
IDESIN	Index for design point calculation
AK1	constant in Eq.(A.3.6)'
AK2	constant in Eq.(A.3.7)' and (A.3.8)'
AK3	constant in Eq.(A.3.1)' and (A.3.2)'
VZ1	axial velocity at blade inlet
VZ2	axial velocity at blade outlet
UR1	rotor blade speed at blade inlet
R1	radius at blade inlet
R2	radius at blade outlet

(3) Output Variables:

DEQS	equivalent diffusion ratio at design point, D_{eq}^*
DEQN	equivalent diffusion ratio , D_{eq}
SITACS	dimensionless momentum thickness at design point, $(\frac{\theta}{c})^*$
SITACN	dimensionless momentum thickness, $(\frac{\theta}{c})$
BET2N	blade outlet angle
OMEGAN	total pressure loss coefficient

(4) Usage:

```
CALL WICGSL(OMEGAS, SIGUMA, BET1S, BET2S, AINCIS, ADEVIS,
        AMACH1, BET1, DEQS, DEQN, SITACS, SITACN,
        BET2N, OMEGAN, X IDESIN, AK1, AK2, AK3, VZ1,
        VZ2, UR1, R1, R2)
```

SUBROUTINE WICSDL

(1) Description:

The subroutine WICSDL is used for the calculation of loss for small droplets on account of the change in momentum thickness of boundary layer due to the presence of such droplets.

In order to estimate the loss pertaining to the increase of momentum thickness due to the existence of small droplets in the boundary layer, Soo's boundary layer analysis for a gas-solids suspension is introduced (Ref. 25). In an isothermal incompressible system, Soo has derived the following equation for suspended particles under the assumption that the number of collisions among particles is negligible when compared to that with the wall,

$$a = \left(\frac{a}{b}\right)\left(\frac{\delta}{x}\right) - \frac{4a^2}{3b^2}\left(\frac{\delta}{x}\right)^{3/4} + \frac{4a^3}{3b^3}\left(\frac{\delta}{x}\right)^{1/2} - \frac{4a^4}{b}\left(\frac{\delta}{x}\right)^{1/4} + \frac{4a^5}{b^5}\ln\left[1 + \frac{b}{a}\left(\frac{\delta}{x}\right)^{1/4}\right] \qquad \text{(A.3.9)}$$

where

$$a = \frac{0.0225\left(\frac{\bar{\mu}}{U\rho_0 x}\right)^{1/4}}{0.1402\left(\frac{\rho_{p0}}{\rho_0}\right) + 0.0972}$$

$$b = \frac{\frac{1}{2\sqrt{\pi}} \frac{\rho_{p_0}}{\rho_0} \frac{U_{pw}\sqrt{\langle U_{pw}^2 \rangle}}{U^2}}{0.1402\left(\frac{\rho_{p_0}}{\rho}\right) + 0.0972}$$

Neglecting shear due to impact of solid particles, Soo derived the following equation.

$$\frac{\delta}{x} = 0.37 \left(\frac{Ux\rho_0}{\mu}\right)^{-1/5} \Big/ \left(1+1.442\,\rho_{p_0}/\rho_0\right)^{0.8} \qquad (A.3.10)$$

The boundary layer thickness, δ, can be obtained from Eqs. (A.3.9) or (A.3.10). In the present model, Eq. (A.3.10) was used.

The momentum thickness, due to liquid phase, θp, is given by

$$\frac{\theta_p}{\delta} = \left(\frac{U_p - U_{pw}}{U_p}\right)^2 \frac{m}{(1+m)\ (2+m)} - \left(\frac{\rho_{p_0} - \rho_{pw}}{\rho_{p_0}}\right) \cdot \frac{U_{pw}}{U_p} \cdot \frac{1}{\alpha+1}$$

$$+ \left(\frac{\rho_{p_0} - \rho_{pw}}{\rho_{p_0}}\right) \left(\frac{U_p - U_{pw}}{U_p}\right)^2$$

$$\times \left[\frac{\Gamma(\frac{2}{m}+1)\ .\ \Gamma(\alpha+1)}{\Gamma(\frac{2}{m}+\alpha+2)} - \frac{\Gamma(\frac{1}{m}+1)\ .\ \Gamma(\alpha+1)}{\Gamma(\frac{1}{m}+\alpha+2)}\right] \qquad (A.3.10)$$

where α and m are constants associated with distribution of velocity and density of liquid phase in the boundary layer namely

$$u_p = U_{pw} + (U_p - U_{pw})\left(\frac{y}{\delta}\right)^{1/m}$$

$$\rho_p = \rho_{pw} - (\rho_{p_0} - \rho_{pw})\left(1 - \frac{y}{\delta}\right)^{\alpha}$$

For the case of solid, spherical particles of 100 and 200μm in diameter in air moving at room conditions with a velocity of 50 to 100 fps, Soo has obtained the following values for the various quantities.

$n = 7$, $m = 1.25$, $\alpha = 2.30$,

$$\frac{U_p - U_{pw}}{U_p} = 0.812, \quad \frac{\rho_{pw}}{\rho_{p_0}} = 1.451$$

Utilizing the above values, Eq. (A.3.10) becomes

$$\frac{\theta_p}{\delta} = 0.1402$$

Following the procedure of Lieblein, the total pressure loss coefficient due to the increase of momentum thickness, $\theta_{p,R}$, because of the existence of small droplets in the boundary layer over rotor blade surface, $\bar{\omega}_{\theta,R}$, can be expressed as follows:

$$\omega_{\theta,R} = \left(\frac{\theta_{p,R}}{c}\right) \frac{2\sigma}{\cos\beta_2} \left(\frac{\cos\beta_1}{\cos\beta_2}\right)^2$$

Similarly, the total pressure loss coefficient due to the increase of momentum thickness, $\theta_{p,S}$, because of the existence of small droplets in the boundary layer on stator blade surface $\bar{\omega}_{\theta,S}$, can be expressed as follows:

$$\omega_{\theta,S} = \left(\frac{\theta_{p,S}}{c}\right) \frac{2\sigma}{\cos\alpha_3} \left(\frac{\cos\alpha_2}{\cos\alpha_3}\right)^2$$

The stagnation pressure losses corresponding to $\overline{\omega}_{\theta,r}$ and $\overline{\omega}_{\theta,S}$ can be written as follows.

$$\Delta P_{\theta,R} = \frac{1}{2}\rho_1 W_1^2 \overline{\omega}_{\theta,R}$$

$$\Delta P_{\theta,S} = \frac{1}{2}\rho^2 V_2^2 \overline{\omega}_{\theta,S}$$

Thus, the total pressure loss across a stage due to the increase of momentum thickness because of the existence of small droplets in a boundary layer is given by

$$\Delta P_\theta = \Delta P_{\theta,R} + \Delta P_{\theta,S}$$

(2) Input Variables

CHORD	chord length
SIGUMA	solidity
BETA1	blade inlet flow angle
BETA2	blade outlet flow angle
UG	average flow velocity
RHOG	density
AMASSW	mass flow rate
AREA	flow area
VZ	axial velocity
IPRINT	index for printout

(3) Output Variables:

OMEGAP	total pressure loss coefficient

SUBROUTINE WICSTL

(1) Description:

The subroutine WICSTL is used for the calculation of loss due to Stokesian drag of droplets in the free stream of blade passage.

In view of the assumption pertaining to motion of small droplets (with zero relative velocity with respect to gas phase), the total pressure loss due to Stokesian drag becomes zero for small droplets.

For large droplets, the model introduced is described below.

The large droplets move with substantial relative velocity with respect to the gas phase and have equal probability of motion in all directions. However, regarding the latter aspect, the droplets are divided into two subclasses with a direction of motion for each class, specified with respect to the gas phase velocity vector. The number of droplets impacting on the blade surface is then proportional to the blade surface area projection normal to the velocity vectors for the two subclasses of droplets.

Referring to Fig. A.3.2., the two subclasses are shown as (1) and (2) which have direction of motion given by γ_1, and γ_2 relative to the gas phase velocity vector. The total number of droplets in subclass (1) is proportional to angle $2\gamma_1$ and those in subclass (2) is proportional to angle $2\gamma_1$ (180 - $2\gamma_1$). The relative velocity between the gas phase and droplets of subclass (1) is given by the difference between V_{g_1} and the component of V_p (the velocity of drop-

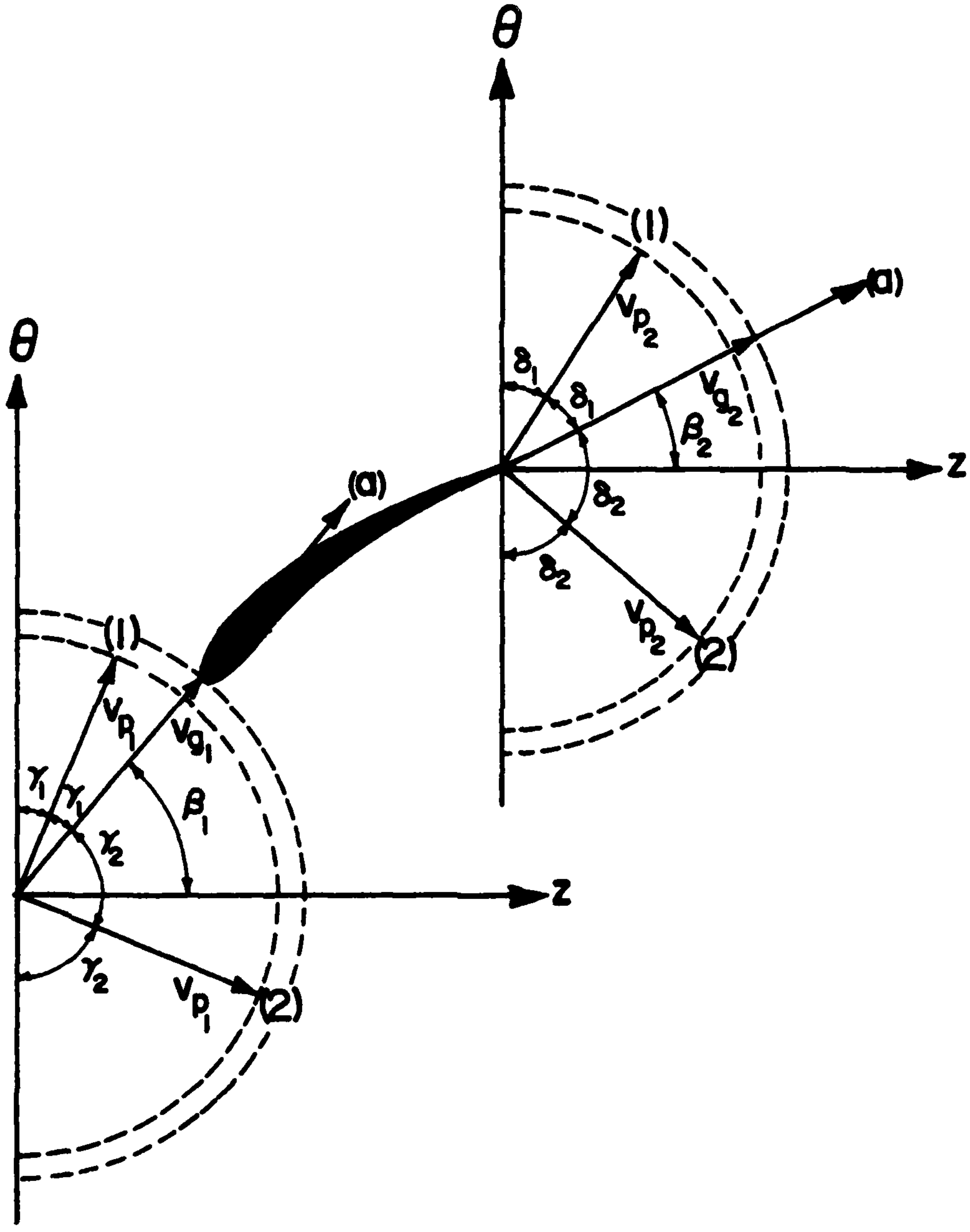

Fig. A.3.2 Model for Motion of Large Droplet

lets in subclass (1) in the direction of V_{g_1}. Similarly the relative velocity between the gas phase and the droplets of subclass (2) is given by the difference between V_{g_1} and the component of V_{p_2} in the direction of V_{g_1}. Thus for droplets of subclass (1) the relative velocity is given by the relation,

$$V_{g_1} - V_{p_1} \cos \gamma_1$$

and for droplets of subclass (2), the relative velocity is given by the relation,

$$V_{g_1} - V_{p_2} \cos \gamma_2$$

In Fig. A.3.2, the blade outlet conditions are also shown. As at the blade inlet section the relative velocities between the gas phase and droplets of subclasses (1) and (2) may be written as follows:

$V_{g_2} - V_{p_1} \cos \delta_1$ for subclass (1), and

$V_{g_2} - V_{p_2} \cos \delta_2$ for subclass (2).

where δ_1 is the inclination of the mean velocity vector for subclass (1) and δ_2, the inclination of the mean velocity vector at outlet, designated V_{g_2}. Once again, at the outlet section, the number of droplets in subclass (1) is proportional to angle $2\delta_1$, and the number of droplets in subclass (2) is proportional to angle $2\delta_2$, or $(180-2\delta_1)$. It is clear that the total number of droplets is divided into two new subclasses at the outlet, based on the directions of motion of droplets relative to the gas phase velcocity. The two subclasses at the outlet are the output from the blade row for the given initial and operating conditions.

Based on the foregoing model of motion of large droplets the total pressure loss coefficient due to the Stokesian drag of large water droplets in a rotor passage, $\bar{\omega}_{s,R}$, can be estimated as follows:

The Stokesian drag of water droplets across a rotor blade is given by

$$D = C_D \frac{1}{2} \rho_{g_1} (W_{g_1} - W_{p_1})^2 A_p N_{d,r}$$

Where W_{g_1} and W_{p_1} are relative velocities of gaseous phase and droplets at rotor inlet, A_p, the project area of a droplet, and $N_{d,r}$, the number of droplets that exist in rotor passage. Referring to Fig. A.3.3, the Stokesian drag, D, can also be written as

$$D = (P_{01,r} - P_{02,r}) A_R$$

where $P_{01,r}$ and $P_{02,r}$ are total pressure at station (1) and (2) in rotor coordinate system, and A_R is the average flow area in a rotor blade passage.

From the above equations, the total pressure loss across a rotor blade due to the Stokesian drag, $\Delta P_{s,R}$ becomes

$$P_{s,R} = c_D \frac{1}{2} \rho_{g_1} (W_{g_1} - W_{p_1})^2 A_p N_{d,R}/A_R = D/A_R$$

By definition, the total pressure loss coefficient across a rotor blade due to Stokesian drag, $\bar{\omega}_{s,R}$, can be obtained as follows:

$$\bar{\omega}_{s,R} = \frac{\Delta P_{s,R}}{\frac{1}{2}\rho_1 W_{g_1}^2} = c_D (W_{g_1} - W_{p_1})^2 A_p N_{d,R}/W_{g_1}^2 A_R = \frac{D/A_R}{\frac{1}{2}\rho_1 W_{g_1}^2}$$

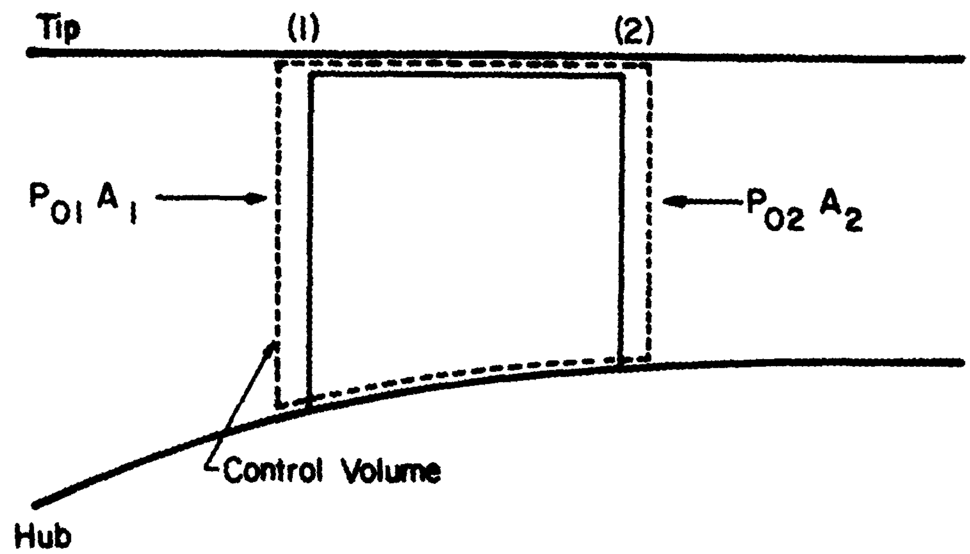

Fig. A.3.3 Control Volume across a Blade

Similarly, the total pressure loss across a stator blade due to Stokesian drag, $\Delta P_{s,S}$ becomes

$$\Delta P_{s,S} = c_D \frac{1}{2} \rho_{g_2} (V_{g_2}^2 - V_{p_2}^2) A_p N_{d,S}/A_S$$

and the total pressure loss coefficient across a stator blade due to the Stokesian drag, $\bar{\omega}_{s,S}$, can be obtained as follows:

$$\bar{\omega}_{s,S} = \frac{\Delta P_{s,S}}{\frac{1}{2}\rho_2 V_2^2} = c_D (V_{g_2}^2 - V_{p_2}^2) A_p N_{d,S}/A_S$$

Thus, the total pressure loss across a stage due to Stokesian drag is given by

$$\Delta P_S = \Delta P_{s,R} + \Delta P_{s,S}$$

(2) Input Variables:

ISTAGE	stage at which performance calculation is carried out
IROTOR	index for rotor or stator
DAV	nominal droplet diameter
W1	relative velocity at rotor inlet
W2	relative velocity at rotor outlet
DELV	relative velocity between gas phase and droplet
V2	absolute velocity at stator inlet
V3	absolute velocity at stator outlet
WMASS	mass flow rate of droplet
VZ	axial velocity
N	station number (Fig.5.1)
BETA1	relative flow angle at rotor inlet
BETA2	relative flow angle at rotor outlet

ALFA2	absolute flow angle at stator inlet
ALFA3	absolute flow angle at stator outlet
MMASS	mass flow rate of mixture

(3) Output Variables:

DELVU2	relative velocity between gas phase and large droplet in subclass (1) at blade outlet
DELVL2	relative velocity between gas phase and large droplet in subclass (2) at blade outlet
OMEGRU	total pressure loss coefficient across rotor due to Stokesian drag in subclass (1)
OMEGRL	total pressure loss coefficient across rotor due to Stokesian drag in subclass(2)
OMEGSU	total pressure loss coefficient across stator due to Stokesian drag in subclass (1)
OMEGSL	total pressure loss coefficient across stator due to Stokesian drag in subclass (2)
DRAGRU	drag force due to large droplet in subclass(1)
DRAGRL	drag force due to large droplet in subclass(2)
DRAGSU	drag force due to small droplet in subclass(1)
DRAGSL	drag force due to small droplet in subclass (2)
REAVE	average Reynolds number

(4) Usage:

```
CALL WICSTL (ISTAGE, IROTOR, DAV, W1,W2, DELV, V2, V3,
             WMASS, VZ, N, BETA1, BETA2, ALFA2, ALFA3,
             MMASS, DELVU2, DELVL2, OMEGRU, OMEGRL, OMEGSU,
             OMEGSL, DRAGRU, DRAGRL, DRAGSU, DRAGSL, REAVE)
```

SUBROUTINE WICFML

(1) Description:

The subroutine WICFML is used for the calculation of loss due to film formed on blade surface when large droplets are present either by themselves or along with small droplets.

The momentum gained by the thick water film on the rotor blade surface is given by $\dot{m}_{film} V_{film}$ per unit blade length, where $\dot{m}_{film}$ is the mass flow rate of water film on the rotor blade per unit blade length and V_{film} is the mean velocity of water film.

Considering the difference in viscosity between the two phases, the velocity of water film can be estimated as follows:

$$V_{film} = \frac{1}{2} \overline{W}_g \frac{\mu_g}{\mu_1}$$

where $\overline{W}_g$ is the mean velocity of gaseous phase, and μ_g and μ_1 are the viscosities of gaseous and liquid phases, respectively.

The foregoing momentum can be transformed into an equivalent drag coefficient as follows.

$$c_{D_f} = \dot{m}_{film} V_{film} / \frac{1}{2} \rho_{g_1} \overline{W}_g^2 c$$

where ρ_{g_1} is blade inlet density of gaseous phase, and c is the chord length of the blade.

The drag coefficient can then be expressed in the form of a total pressure loss coefficient as follows:

$$c_{Df} \frac{1}{2} \rho_{g_1} \overline{W}_{g_1}^2 c = \Delta P_f \,.\, s \,.\, \cos \beta_m$$

where s is the blade pitch and β_m is mean flow angle. Noting that $V_z = \overline{W}_g \cos \beta_m$, one obtains the relation, namely

$$\Delta P_f / \tfrac{1}{2} \rho_{g_1} V_z^2 = c_{D_f} \left(\frac{c}{s}\right) \frac{1}{\cos^3 \beta_m}$$

Since $\overline{W}_{g_1} = V_z/\cos\beta_1$, the total pressure loss coefficient due to the momentum gained by the thick film on the rotor blade surface can be written as follows:

$$\overline{\omega}_f = \Delta P_f / \tfrac{1}{2} \rho_{g_1} W_{g_1}^2 = c_{Df} \left(\frac{c}{s}\right) \frac{\cos^2 \beta_1}{\cos^3 \beta_m}$$

(2) Input Variables:

WG1	flow velocity at blade inlet
WG2	flow velocity at blade outlet
FMASS	mass flow rate of water film on blade surface per unit blade length
RHOG1	density
CHORD	chord length
SIGUMA	solidity
BETA1	blade inlet flow angle
BETA2	blade outlet flow angle

(3) <u>Output Variables</u>:

CDF	drag coefficient
OMEGAF	total pressure loss coefficient

(4) Usage:

```
CALL WICFML (WG1,WG2, FMASS, RHOG1, CHORD, SIGUMA, BETA1,
            BETA2, CDF, OMEGAF)
```

SUBROUTINE WICRSL

(1) Description:

The subroutine WICRSL is used for the calculation of loss due to the rough surface when large droplets are presented either by themselves or along with small droplets.

Using the experimental results on pipes roughened with sand, L. Prandtl and H. Schlichting carried out a correlation to obtain the friction coefficient on a rough place (Ref. 26). The correlation was based on the logarithmic velocity distribution law for rough pipes in the form, namely

$$\frac{u}{v^*} = 2.5 \ln\left(\frac{y}{k}\right) + B$$

where v* is friction velocity; k is roughness of surface, and B is a roughness function which depends on the roughness parameter, v*k/r.

In the completely rough regime, they obtained the following relation for the drag coefficient for a plate.

$$c_{Dr} = \left(1.81 + 1.62 \log_{10} \frac{x}{k}\right)^{-2.5}$$

In the present case, x is replaced by the chord length, c, and the surface roughness k is assumed to be the same as the order of mean diameter of large droplets.

Thus, the total pressure loss coefficient due to turbulent friction over a rough film surface on a rotor becomes the following.

$$\bar{\omega}_r = c_{Dr} \left(\frac{c}{s}\right) \frac{\cos^2 \beta_1}{\cos^3 \beta_m}$$

(2) Input Variables:

SIGUMA	solidity
BETA1	blade inlet flow angle
BETA2	blade outlet flow angle
CHORD	chord length
DL	droplet diameter

(3) Output Variables:

CDR	drag coefficient
OMEGAR	total pressure loss coefficient

(4) Usage:

```
CALL WICRSL (SIGUMA, BETA1, BETA2, CHORD, DL, CDR,
             OMEGAR)
```

SUBROUTINE WICVT

(1) Description:

The subroutine WICVT is used for the calculation of velocity triangle components and angles. Typical velocity diagram for a compressor stage is presented in Fig. A.2.1.

(2) Input Variables:

ISTAGE	stage at which performance calculation is carried out
ASPEED	acoustic speed

ALFA1	absolute flow angle at rotor inlet
VZ	axial velocity
AK1	constant in Eq. (A.3.6)'
AK3	constant in Eq. (A.3.1)' and (A.3.2)'

(3) Output Variables:

V1	absolute velocity at rotor inlet
VS1	tangential component of V1
WS1	tangential component of W1
BETA1	relative flow angle at rotor inlet
W1	relative velocity at rotor inlet
BETA2	relative flow angle at rotor outlet
WS2	tangential component of W2
VS2	tangential component of V2
ALFA2	absolute flow angle at rotor outlet
W2	relative velocity at rotor outlet
VZ	absolute velocity at rotor outlet
ALFA3	absolute flow angle at stator outlet
V3	absolute velocity at stator outlet

(4) Usage:

```
CALL WICVT (ISTAGE, ASPEED, ALFA1, VZ, V1, VS1, WS1,
           BETA1, W1, BETA2, WS2, VS2, ALFA2, W2, V2,
           ALFA3, V3, AK1, AK3)
```

SUBROUTINE WICCEN

(1) Description:

The subroutine WICCEN is used for the calculation of spanwise replacement of droplets due to centrifugal action.

Three forces act on a droplet moving through a fluid: (1) the external force consisting of gravitational and and centrifugal forces; (2) the buoyancy force, which acts parallel to the external force, but in the opposite direction; and (3) the drag force, which appears whenever there is relative motion between the droplet and the fluid, and acts parallel to the direction of motion but in the opposite direction. In the present case, the direction of motion of a droplet relative to the fluid is not parallel to the direction of the external and buoyant forces, and therefore the drag force makes an angle with the other two forces. However, under the one-dimensional approximation, the lines of action of all forces acting on the droplet are co-linear and therefore the forces may be added in obtaining a balance of momentum, as follows:

$$\frac{m}{g_c}\frac{du}{dt} = F_e - F_b - F_D$$

where F_e, F_b and F_D are the external, buoyancy and drag forces respectively.

The external force can be expressed as the product of mass and acceleration, a_e, of the droplet due to this force, and therefore

$$F_e = \frac{m}{g_c} a_e$$

In the present case, because of the large rotor speeds, the centrifugal acceleration is far larger than the gravitational acceleration. Thus

$$a_e = r\omega^2$$

where r is the radius and ω, the angular velocity. The acceleration can also be written as follows:

$$a_e = V_\theta^2/r$$

where V_θ is the circumferential velocity of the droplet. For droplets passing through a rotor blade passage, the circumferential component of the relative velocity, W_θ, should be used in place of V_θ. When there is a large change in whirl velocity between the inlet and outlet of a blade row, a mean value of velocity may be more applicable.

The buoyancy force is, by Archimedes' Principle, the product of the mass of the fluid displaced by the droplet and the acceleration from the external force. The mass of fluid displaced is $(m/\rho_w)\rho_g$, where ρ_w is the density of water and ρ_g is the density of the surrounding fluid. The buoyancy force is then given

$$F_b = m\rho_g a_e/\rho_w g_c$$

The drag force is expressed by the relation,

$$F_d = C_D \frac{\rho_g u^2}{2\, g_c} A_p$$

where C_D is the drag coefficient and A_p is the projected area of the droplet measured in a plane perpendicular to the direction of motion of the droplet. The drag coefficient

C_D can be expressed in a general form as follows:

$$C_D = b_1/Re^n$$

where Re is the Reynolds number based on relative velocity between gas and droplet. The constants b_1 and n are as follows.

$b_1 = 24.0$, $n = 1.0$ when $Re < 1.9$
$b_1 = 18.5$, $n = 0.6$ when $1.9 < Re < 500$
$b_1 = 0.44$, $n = 0.0$ when $500 < Re < 200{,}000$.

The equation of droplet motion then becomes the following:

$$\frac{du}{dt} = A/r - B\,u^{2-n}$$

where

$$A = (W_\theta)^2_{ave} \cdot (1-\rho_g/\rho_w),$$

$$B = 3\,u^n b_1 \rho_g^{1-n}/4\rho_w D^{1+n}, \text{ and}$$

D being the average droplet diameter. Over a small time interval, the equation of motion can be written as follows:

$$\Delta u = (A/r - B \cdot u^{2-n})\,\Delta t$$

This equation can be used to determine the radial location of a droplet in a stage as follows:

(i) Select the initial values for u_1 and r_1.

(ii) Calculate the Reynolds number to determine the values of b_1 and n.

(iii) Calculate A and B.

(iv) Calculate the change of u during time interval Δt.

(v) Calculate the new velocity u_2.

$$u_2 = u_1 + \Delta u$$

(vi) Calculate the change in location of droplet in terms of Δr.

$$\Delta r = (u_1 + u_2) / 2.0 \cdot \Delta t$$

(vii) Calculate the new radial location.

$$r_2 = r_1 + \Delta r$$

(viii) Repeat the calculation for new value of u_2 and r_2 and progressively extend the calculation.

The time interval should be sufficiently small in order to obtain reasonable accuracy. As stated in Section 2.1.3 in Chapter II of this Report, the length between the leading and trailing edges of a blade is divided into ten steps. The time interval Δt is then given by the relation, namely

$$\Delta t = \frac{\text{chord}}{V} \times \frac{1}{10}$$

where V is the velocity of moisture in the blade passage.

(2) Input Variables:

RZERO	droplet spanwise location at rotor inlet
UZERO	droplet spanwise velocity at rotor inlet
DD	droplet diameter
VZ	axial velocity
DELZZ	axial length of a stage
ALFAAV	average flow angle
FN	rotor blade rotational speed

IRS	index for rotor or stator
RHOGAS	density
RHUB	radius at hub
XG	mass fraction of gas phase
XA	mass fraction of dry air
XVV	mass fraction of vapor
XCH4	mass fraction of methane
RTIPIN	radius at blade tip

(3) Output Variables:

R2	droplet spanwise location blade outlet
U2	droplet spanwise velocity at blade outlet
ITIP	index for droplet spanwise location
VZTIME	time in which flow pass through a stage

(4) Usage:

```
CALL WICCEN (RZERO, VZERO, DD, VZ, DELZZ, ALFAAV, FN,IRS,
             RHOGAS, RHUB, R2, U2, ITIP, VZTIME, XG, XA,
             XVV, XCH4, RTIPIN)
```

SUBROUTINE WICDMS

(1) Description:
The subroutine WICDMS is used for the calculation of amount of small droplets which is centrifuged.

(2) Input Variables:

IPRINT	index for printout
IRAD	index for spanwise location

AMASW1	mass flow rate of water at rotor inlet
AMASWT	mass flow rate of droplet
AMASW	mass flow rate of droplet
R1	droplet spanwise location rotor inlet
R2	droplet spanwise location at rotor outlet
STAREA	streamtube area
RSTAVE	radius of streamtube at its center
RTIP	radius at blade tip

(3) Output Variables:

DMIN	amount of water that is centrifuged and enters into a streamtube
DMOUT	amount of water that is centrifuged and leavesfrom a streamtube
AMASW2	mass fraction of water at rotor outlet after correction for centrifugal action
DELMAS	net amount of water that is centrifuged

(4) Usage:

```
CALL WICDMS (IPRINT, IRAD, AMASW1, AMASWT, AMASW, R1,
            R2, STAREA, RSTAVE, RTIP, DMIN, DMOUT,
            AMASW2, DELMAS)
```

SUBROUTINE WICDML

(1) Description:

The subroutine WICDML is used for the calculation of amount of large droplets which is centrifuged.

(2) Input Variables;

IPRINT	index for printout
IRAD	index for spanwise location
AMASW1	mass flow rate of water at rotor inlet
AMASWT	mass flow rate of droplet
AMASW	mass flow rate of droplet
R1	droplet spanwise location rotor inlet
R2	droplet spanwise location at rotor outlet
STAREA	streamtube area
RSTAVE	radius of streamtube at its center
RTIP	radius at blade tip

(3) Output Variables:

DMIN	amount of water that is centrifuged and enters into a streamtube
DMOUT	amount of water that is centrifuged and left from a streamtube
AMASW2	mass fraction of water at rotor outlet after correction for centrifugal action.
DELMAS	net amount of water that is centrifuged

(4) CALL WICDML (IPRINT, IRAD, AMASW1, AMASWT, AMASW, R1, R2, STAREA, RSTAVE, RTIP, DMIN, DMOUT, AMASW2, DELMAS)

SUBTROUTINE WICDRG

(1) Description:

The subroutine WICDRG is used for the calculation of drag

force on droplet.

(2) Input Variables:

D	droplet nominal diameter
DELV1	relative velocity between droplet and gas phase at blade inlet
RHGAS1	density of gas phase at blade inlet
RHGAS2	density of gas phase at blade outlet

(3) Output Variables:

CD2	drag coefficient
DELV2	relative velocity between droplet and gas phase at blade outlet
DRAG1	drag force
RE	Reynolds number

(4) Usage:

CALL WICDRG (D, DELV1, RHGAS1, RHGAS2, CD2, DELV2, DRAG1, RE)

SUBROUTINE WICMAC

(1) Description:

Subroutine WICMAC calculates the Mach number in the gas-water droplet mixture. First the acoustic speed in gaseous phase is determined by iteration as follows:

(i) Assume Mach number and calculate static temperature and density.

$$t = (1 + \frac{\gamma-1}{2} M^2)^{-1} T_{01}$$

$$\rho = (1 + \frac{\gamma-1}{2} M^2)^{-1/(\gamma-1)} P_{01}/RT_{01}$$

(ii) Calculate acoustic speed in gaseous phase

$$a_g = (\gamma R t g_c)^{0.5}$$

(iii) Calculate the axial velocity

$$V_z = \dot{m}/\rho A$$

(iv) Calculate absolute velocity

$$V_1 = V_3/\cos \alpha_1$$

(v) Calculate Mach number

$$M_1 = V_1/a_g$$

Compare the calculated Mach number with the assumed value in (i). Iterate steps (i) to (v) until the desired accuracy is obtained. After determing the acoustic speed in gaseous phase, Fucnction WICASD is called to determine the acoustic speed in droplet-laden gas flow.

(2) Input Variables:

ISTAGE	stage number
AMASSM	mixture mass flow rate

T01G	total temperature of gaseous phase
PRES	total pressure
XW1	total water content
ALFA	stator outlet angle of the previous stage
RMIX	gas content of gaseous phase
CPMIX	specific heat at constant pressure for gaseous phase

(3) Output Variables:

M	Mach number
VZ	axial velocity
C	acoustic speed in mixture

(4) Usage:

CALL WICMAC (ISTAGE, AMASSM, T01G, PRES, M, VZ, C, XW1, ALFA, RMIX, CPMIX)

FUNCTION WICASD

(1) Description:

Function WICASD calculates the acoustic speed in droplet-laden gas flow. The following equation is used (Ref.27).

$$a = \left[\left\{ (1-\sigma_v)\rho_g + \sigma_v \rho_w \right\} \left\{ \frac{1-\sigma_v}{\rho_g a_g^2} + \frac{\sigma_v}{\rho_w a_w^2} \right\} \right]^{-\frac{1}{2}}$$

where
a_g = acoustic speed in gaseous phase

a_w = acoustic speed in water

ρ_g = density of gaseous phase

ρ_w = density of water

σ_v = particulate liquid volume fraction

x_w = particulate liquid mass fraction

$$\sigma_v = x_w \rho_g / \left[\rho_w - x_w (\rho_w - \rho_g) \right]$$

(2) Input Variables:

XW	total water content
RHOG	density of gas phase
CG	acoustic speed of gaseous phase

(3) Output Variable:

WICASD	acoustic speed in gas-water droplet mixture

(4) Usage:

WICASD (XW, RHOG, CG)

SUBROUTINE WICBOA

(1) Description:

Subroutine WICBOA calculates the blade outlet flow angle based on Swan's correlation curves (Ref.24). Swan's curves and the concept of equivalent diffusion ratio are also described in Subroutine WICGSL.

(2) Input Variables:

OMEGAS	total pressure loss coefficient at design point
SIGUMA	solidity
BET1S	blade inlet angle at design point
BET2S	blade outlet angle at design point
AINCIS	incidence at design point
ADEVIS	deviation at design point
AMACH1	blade inlet Mach number
BET1	blade inlet flow angle

(3) Output Variables:

DEQS	equivalent diffusion ratio at design point
DEQN	equivalent diffusion ratio
SITACS	ratio of wake momentum thickness to chord design point
SITACN	ratio of wake momentum thickness to chord
BET2N	blade outlet angle

(4) Usage:

```
CALL WICBOA (OMEGAS, SIGUMA, BET1S, BET2S, AINCIS, ADEVIS,
            AMACH1, BET1, DEQS, DEQN, SITACS, SITACN, BET2N)
```

SUBROUTINE WICEDD

(1) Description:

Subroutine WICEDD is called in Subroutine WICBOA and WICGSL. The equivalent diffusion ratio at design point, D^*_{eq}, and the ratio of wake momentum thickness to chord at design point, $(\frac{\theta}{c})^*$, are obtained from the following equations:

$$D^*_{eq} = \frac{\cos\beta_2}{\cos\beta_1} \frac{V_{z1}}{V_{z2}} \left(1.12 + 0.61 \frac{\cos^2\beta_1}{\sigma} K\right) \cdot AK3$$

$$\left(\frac{\theta}{c}\right) = \frac{\bar{\omega}^* \cos\beta_2^*}{2\sigma} \left(\frac{\cos\beta_2^*}{\cos\beta_1^*}\right)^2$$

where

$$K = \tan\beta_1^* - \frac{r_1}{r_1} \frac{V_{z2}}{V_{z1}} \tan\beta_1^* - \frac{\omega r_1}{V_{z1}} \left(1 - \frac{r_2^2}{r_1^2}\right)$$

(2) Input Variables:

AK3	constant, normally one
VZ1	axial velocity at blade inlet
VZ2	axial velocity at blade outlet
UR1	rotor blade speed at rotor inlet
R1	radius at blade inlet
R2	radius at blade outlet
BET1S	blade inlet flow angle at design point
BET2S	blade outlet flow angle at design point
SIGUMA	solidity
OMEGAS	total pressure loss coefficient at design point

(3) Output Variables:

DEQS	equivalent diffusion ratio at design point
SITACS	ratio of wake momentum thickness to chord at design point

(4) Usage:

```
CALL WICEDD (AK3, VZ1, VZ2, UR1, R1, R2, BET1S, BET2S,
            SIGUMA, OMEGAS, DEQS, SITACS)
```

FUNCTION WICED

(1) Description:

Function WICED is called in Subroutines WICBOA and WICGSL. The equivalent diffusion ratio is obtained from the following equation.

$$D_{eq} = \frac{\cos\beta_2}{\cos\beta_1} \frac{V_{z_1}}{V_{z_2}} \left[1.12 + k\,(i-i^*)^{1.43} + 0.61 \frac{\cos\beta_1}{\sigma} K\right] . \ AK3$$

where

$$K = \tan\beta_1 - \frac{r_2}{r_1} \frac{V_{z_2}}{V_{z_1}} \tan\beta_1 - \frac{\omega r_1}{V_{z_1}} \left(1 - \frac{r_2^2}{r_1^2}\right)$$

and where k = 0.0117 for NACA 65 (A_{10}) blades and k = 0.007 for the C4 airfoils.

(2) Input Variables:

AK3 constant, normally one

VZ1 axial velocity at blade inlet

VZ2 axial velocity at blade outlet

UR1 rotor blade speed at rotr inlet

R1 radius at blade inlet

R2 radius at blade outlet

BET1 blade inlet flow angle

BET2 blade outlet flow angle

SIGUMA solidity

AINCIS incidence at design point

AINCI incidence

(3) Output Variable:

WICED equivalent diffusion ratio

(4) Usage:

WICED (AK3, VZ1, VZ2, UR1, R1, R2, BET1, BET2, SIGUMA, AINCIS, AINCI)

FUNCTION WICMTK

(1) Description:

Function WICMTK is called in Subroutines WICBOA and WICGSL. The ratio of wake momentum thickness and chord are obtained from the following equations.

$$\frac{\theta}{c} = \left(\frac{\theta}{c}\right)^* + (0.827\ M_1 + 2.675\ M\ )\ (D_{eq} - D_{eq}*)^2 .\ AK2$$

for $D_{eq} > D_{eq}*$

$$\frac{\theta}{c} = \left(\frac{\theta}{c}\right)^* + (2.80\ M_1 - 8.71\ M_1^2 + 9.36\ M_1^3)\ (D_{eq} - D_{eq}*)^2\ .\ AK2$$

for $D_{eq} < D_{eq}*$

(2) Input Variables:

AK2	constant, normally one
SITACS	ratio of wake momentum thickness to chord at design point
AMACH1	blade inlet Mach number
DELDEQ	difference between equivalent diffusion ratio and equivalent diffusion ratio at design point.

(3) Output Variables:

WICMTK	ratio of wake momentum thickness to chord

(4) Usage:

WICMTK (SI[illegible], AMACH1, DELDEQ, AK2)

FUNCTION WICLOS

(1) Description;

Function WICLOS is called in Subroutine WICGSL and calculates the total pressure loss coefficient from the following equation:

$$\bar{\omega} = \left(\frac{\theta}{c}\right) \frac{2\sigma}{\cos\beta_2} \left(\frac{\cos\beta_1}{\cos\beta_2}\right)^2$$

(2) Input Variables:

BET1	blade inlet flow angle
BET2	blade outlet flow angle
SIGUMA	solidity
SITA	ratio of momentum thickness to chord

(3) Output Variable:

WICLOS	total pressure loss coefficient

(4) Usage:

WICLOS (BET1, BET2, SIGUMA, SITA)

SUBROUTINE WICIRS

(1) Description:

Subroutine WICIRS is called at outlet of rotor and performs the calculation of droplet impingement and rebound in rotor passage for small droplet.

(2) Input Variables:

ISTAGE	stage number
RTIPIN	blade tip radius
XW1	mass fraction of small droplet

XG	mass fraction of gaseous phase
RHQG1	density of gaseous phase
BETA1	rotor inlet relative flow angle
W1	rotor inlet relative velocity

(3) Output Variables:

WW1	amount of water that impacts stagnation region of blade
WW2	amount of water that impact aft of blade
WW	total amount of water that impact blade

(4) Usage:

```
CALL WICIRS (ISTAGE, RTIPIN, XW1, XG, RHOG1, BETA1, W1,
          WW1, WW2, WW)
```

<u>SUBROUTINE WICIRL</u>

(1) Description:

Subroutine WICIRL is called at outlet of rotor and performs the calculation of droplet impingement and rebound in rotor passage for large droplet.

(2) Input Variables:

ISTAGE	stage number
RTIPIN	blade tip radius
XW1	mass fraction of large droplet
XG	mass fraction of gaseous phase
PHOG1	density of gaseous phase
BETA1	rotor inlet relative flow angle
W1	rotor inlet relative velocity

(3) Output Variables:

WW1	amount of water that impacts upper surface of blade
WW2	amount of water that impact lower surface of blade
WW	total amount of water that impact blade surface

(4) Usage:

```
CALL WICIRL (ISTAGE, RTIPIN, XW1, XG, RHOG1, BETA1, W1,
             WW1, WW2, WW)
```

SUBROUTINE WICISS

(1) Description;

Subroutine WICISS is called outlet of stator and performs the calculation of droplet impingement and rebound in stator passage for small droplet.

(2) Input Variables:

ISTAGE	stage number
RTIPIN	blade tip radius
XW	mass fraction of small droplet
XG	mass fraction of gaseous phase
RHOG1	density of gaseous phase
ALFA2	stator inlet absolute flow angle
W1	stator inlet absolute velocity

(3) Output Variables;

WW1	amount of water that impact stagnation region of blade
WW2	amount of water that impact off of blade
WW	total amount of water that impact the blade

(4) Usage:

```
CALL WICISS (ISTAGE TRIPIN, XW, XG RHOG1, ALFA2, W1,
            WW1, WW2, WW)
```

SUBROUTINE WICISL

(1) Description:

Subroutine WICISL is called at outlet of stator and performs the calculation of droplet impingement and rebound in stator passage for large droplet.

(2) Input Variable:

ISTAGE	stage number
RTIPIN	blade tip radius
XW	mass fraction of large droplet
XG	mass fraction of gaseous phase
RHOG1	density of gaseous phase
ALFA2	stator inlet absolute flow angle
W1	stator inlet absolute velocity

(3) Output Variables:

WW1	amount of water that impact upper surface of blade
WW2	amount of water that impact lower surface of blade

WW total amount of water that impact on blade surface

(4) Usage:

CALL WICISL (ISTAGE, RTIPIN, XW, XG, RHOG1, ALFA2, W1, WW1, WW2, WW)

SUBROUTINE WICWAK

(1) Description:

Subroutine WICWAK is called at rotor outlet and stator outlet, and calculates the droplet size of water that is re-entrained at trailing edge of rotor and stator blades.

The size of droplet which is re-entrained into the wake at the blade trailing edge is calculated as follows:

(i) Assume a value for a droplet diamter, d, that is re-entrained into wake.

(ii) Calculate the stability number, SN.

$$SN = \mu_f^2 / \rho_g \sigma d g_c$$

(iii) Calculate the critical Weber number

$$W_e = 12 \left(1 + (SN)^{0.36} \right)$$

(iv) Calculate the largest stable droplet diameter

$$d_{max} = \frac{W_e}{\rho_g} \frac{\sigma g_c}{V_g^2}$$

(v) Compare the assumed droplet diameter with the calculated one. Iterate entire steps until the satisfactory agreement is obtained.

(2) Input Variables:

RHOG density of gaseous phase

V velocity of gaseous phase for small droplet or relative velocity between droplet and gaseous phase for large droplet

(3) Output Variables:

DWAKE droplet size that re-entrained at trailing edge in (ft^3)

DWAKEM droplet size that re-entrained at trailing edge in (μm)

(4) Usage:

CALL WICWAK (RHOG, V, DWAKE, DWAKEM)

SUBROUTINE WICHET

(1) Description:

Subroutine WICHET is called at end of stage to perform the heat transfer calculation between water droplet and gaseous phase. The heat transfer rate can be determined from the following equation

$$\frac{dh}{dt} = h_h A \; (T_g - T_w)$$

where h_h is the heat transfer coefficient, A, the droplet surface area, T_w, the droplet surface temperature, and T_g, the temperature of the surrounding gas. The heat transfer coefficient can be expressed as follows:

$$h_h = \frac{k_a}{D_d} \bullet Nu$$

where k_a is the thermal conductivity of air, and Nu, the Nusselt Number. The Nusselt number can be expressed in terms of the dimensionless groups as follows;

$$Nu = 2.0 + 0.6\,(Re)^{0.50}(Pr)^{0.33}$$

where Re is the Reynolds number based on the relative velocity between the droplet and the surrounding air, and Pr is Prandtl number.

After calculating the temperature rise of the water and gas phase due to the work done by the rotor, the heat transfer calculation is carried out as follows:

(i) Calculate the average droplet diameter, D_d.

(ii) Calculate the number of droplets, N_d .

$$N_d = \frac{\dot{m}_w}{\rho_w \frac{4}{3}\pi(D_d/2)^3} \cdot \frac{\Delta z}{V_z}$$

where $\dot{m}_w$ is the mass flow rate of water phase, ρ_w, the density of water, V_z , the axial direction velocity, and Δz, the axial length of one stage.

(iii) Calculate the droplet surface area, A.

(iv) Calculate the Nusselt number, Nu.

(v) Calculate the heat transfer coefficient, h_h.

(vi) Calculate the stage outlet temperature for droplet and gas without heat transfer, that is

$$T_{g_2} = T_{g_1} + (\Delta T_g)_{wk}$$

$$T_{w_2} = T_{w_1} + (\Delta T_w)_{wk}$$

where $(\Delta T_g)_{wk}$ and $(\Delta T_w)_{wk}$ are the temperature rise of of gas and water due to work done by rotor.

(vii) Calculate the amount of heat transferred from the gas to the droplet.

$$\Delta H = h_h A (T_{g2} - T_{w2})$$

(viii) Calculate the temperatures rise of the droplet and the temperature drop of the surrounding gas.

$$(\Delta H_g)_{ht} = \Delta H / m_g C_s$$

$$(\Delta H_w)_{ht} = \Delta H / m_w C_w$$

where C_w is the specific heat for water and C_s is the humid heat for air-water mixture.

(ix) Calculate the stage outlet temperature for droplet and gas.

$$T_{g_2} = T_{g_1} + (\Delta T_g)_{wk} - (\Delta T_g)_{ht}$$

$$T_{w_2} = T_{w_1} + (\Delta T_w)_{wk} + (\Delta T_w)_{ht}$$

(X) Using the temperature calculated in step (ix), repeat the steps (vii) to (ix) until a desired accuracy is obtained.

(2) Input Variables:

TG1	temperature of gaseous phase at stage inlet
TG3	temperature of gaseous phase at stage outlet
TW1	temperature of droplet at stage inlet
TW3	temperature of droplet at stage outlet
DAVEN2	droplet nominal diameter at stage inlet
DEVEN	droplet nominal diameter at stage outlet
DELZI	length of stage
VZ	axial velocity
WMASS1	mass flow rate of water
VMASS1	mass flow rate of water vapor

AMASS	mass flow rate of dry air
CHMASS	mass flow rate of methane
DPG	specific heat constant pressure to gaseous phase
CPW	specific heat of water
RE	Reynolds number based on relative velocity between droplet and gaseous phase.

(3) Output Variables:

DELIGH	temperature drop in gaseous phase due to heat transfer between water droplet and gaseous phase
DELTWH	temperature rise in droplet due to heat transfer between water droplet and gaseous phase

(4) Usage:

CALL WICHET (TG1, TG3, TW3, DAVEN2, DAVEN, DELZI, VZ,
WMASS1, VMASS1, AMASS, CHMASS, CPG, CPW,
DELIGH, DELTWH, RE)

SUBROUTINE WICMAS

(1) Description:

Subroutine WICMAS is called at end of stage to perform the mass transfer calculation between water droplet and gas phases.

The mass transfer rate can be calculated by the following equation

$$\frac{dm}{dt} = h_m A \, (C_{wb} - C_w)$$

where h_m is the mass transfer coefficient, A, the droplet surface area, C_{wb}, the water vapor concentration at droplet surface , and C_w, the water vapor concentration in fluid flow around droplet.

Since the density represents the mass concentration, and the vapor is almost a perfect gas, the mass transfer rate can be expressed in terms of vapor pressure as follows:

$$\frac{dm}{dt} = h_m A \, (\rho_{wb} - \rho_w)$$

or

$$\frac{dm}{dt} = h_m A \left(\frac{P_{wb}}{T_{wb}} - \frac{P_w}{T_w} \right) \cdot \frac{1}{R_v}$$

where R_v is the gas constant for water vapor, P_{wb}, the vapor pressure at droplet surface, P_w , the vapor pressure in fluid flowing around droplet, T_{wb}, the vapor temperature at droplet surface, and T_w, the vapor temperature in fluid flowing around droplet.

The surface area, A, for the droplet cloud is given by the relation,

$$A = \pi D_d^2 \, N_d$$

where D_d is the average droplet diameter, and N_d, the number of droplets.

The mass transfer coefficient, h_m is expressed as follows:

$$h_m = \frac{D_v}{D_d} \cdot Sh$$

A semi-empirical equation for the diffusion coefficient in gases is given by the following: (Reference 28)

$$D_v = 435.7 \, \frac{T^{3/2}}{p(V_A^{1/3} + V_B^{1/3})^2} \left(\frac{1}{M_A} + \frac{1}{M_B} \right)^{1/2}$$

where D_v is in square centimeters per second, T is in degree Kelvin, p is the total system pressure in newtons per square meter, and V_A and V_B are the molecular volumes of constituents A and B as calculated from the atomic volumes. M_A and M_B are the molecular weights of constituents A and B. For water-air systems, the numerical values of V_A, V_B, M_A and M_B are given as follows:

$$V_A = V_{air} = 29.9 \qquad M_A = M_{air} = 28.9$$

$$V_B = M_{water} = 18.8 \qquad M_B = M_{water} = 18.0$$

When the relative velocity between a single droplet and the surrounding fluid approaches zero, the following relationship is used to determine the mass transfer rate: Sh = 2.0.

Mass transfer rates increase with increase in relative velocity between the droplet and the surrounding air due to the additional mass transfer caused by the convection in the boundary layer around the droplet. The mass transfer coefficient from a spherical droplet can be expressed in terms of dimensionless groups as follows:

$$Sh = 2.0 + k\,(Re)^x (Sc)^y$$

where Re is the Reynolds number based on relative velocity, which expresses the ratio of inertial force to viscous force, and Sc is the Schmidt number, which expressed the ratio of kinetic viscosity to molecular diffusivity.

There is much discussion over the values of x, y, and k. The form most widely applied is the Ranz and Marshall equation which is

$$Sh = 2.0 + 0.6\,(Re)^{0.50}(Sc)^{0.33}$$

The procedure for determining the mass transfer rate is as follows.

(i) Calculate the Sherwood number, Sh.

(ii) Calculate the diffusion coefficient, D_v.

(iii) Calculate the average droplet size, D_d.

(iv) Calculate the mass transfer coefficient, h_m.

(v) Calculate the total number of droplets, N_d.

(vi) Calculate the total surface area for all droplets.

(vii) Calculate the water vapor pressure at droplet surface, P_{wb}, based on the droplet surface temperature, T_s.

(viii) Assume the vapor pressure, p_w, and set $p_w = (p_w)_a$.

(ix) Calculate the mass transfer rate, $\frac{dm}{dt}$.

(x) Calculate the the new value of water mass flow rate.

$$\dot{m}_w = \dot{m}_w - \frac{dm}{dt}$$

(xi) Calculate the new value of vapor mass flow rate.

$$\dot{m}_v = \dot{m}_v + \frac{dm}{dt}$$

(xii) Calculate the specific humidity, W.

$$W = \dot{m}_v/\dot{m}_a$$

where m_a is the air mass flow rate.

(xiii) Calculate the vapor pressure.

(xiv) Compare the calculated value, $(p_w)_c$, with the assumed value $(p_w)_a$.
If $(p_w)_c$ agrees reasonably well with the assumed value $(p_w)_c$ proceed to step (xv). Otherwise, steps (viii) to (xiv) should be repeated.

(xv) Using the determined p_w, the mass transfer rate is calculated Also, the specific humidity can be determined by the following equation:

$$W = 0.6219 \frac{P_w}{P - P_w}$$

(2) Input Variables:

HW1	specific humidity at stage inlet
TW1	temperature of droplet at stage inlet
TW2	temperature of droplet at stage outlet
PP1	pressure of gaseous phase stage inlet
PP2	pressure of gaseous phase at stage outlet
TG1	temperature of gaseous phase at stage inlet
TG2	temperature of gaseous phase at stage outlet
DZ	length of stage
VZ	axial velocity
DDAVE1	droplet nominal diameter at stage inlet
DDAVE2	droplet nominal diameter at stage outlet
AMASS	mass flow rate of air
RE	Reynolds number based on relative velocity between droplet and gaseous phase
VMASS1	mass flow rate of water vapor at stage inlet
WMASS1	mass flow rate of water droplet at stage outlet

(3) Output Variables:

HW2	specific humidity at stage outlet
VMASS2	mass flow rate of water vapor at stage outlet
WMASS2	mass flow rate of water droplet at stage outlet
DMDTAV	average mass transfer rate across stage

(4) Usage:

```
CALL WICMAS (HW1, TW1, TW2, PP1, PP2, TG1, TG2, DZ, PWB1,
            PWB2, PW1, PW2, VZ, DDAVE1, DDAVE2, HW2,
            VMASS1, VMASS2, WMASS1, WMASS2, DMDTAV,
            AMASS, RE)
```

FUNCTION WICMTR

(1) Description:

Function WICMTR is called in Subroutine WICMTR and calculates the mass transfer rate.

(2) Input Variables:

TTG	temperature of gaseous phase
TTW	temperature of water droplet
PPP	pressure of gaseous phase
DAVW	droplet nominal diameter
VZ	axial velocity
DZ	length of stage
MMASS	mass flow rate of mixture
PW	vapor pressure
RE	Reynolds number based on relative velocity between droplet and gaseous phase

(3) Output Variable:

DMDT	mass transfer rate

(4) Usage:

WICMTR (TTG, TTW,PPP, DAVE, VZ, DZ, MMASS, PW , RE)

FUNCTION WICPWB

(1) Description:

Function WICPWB calculates the saturation pressure for water vapor is a function at temperature as follows:

$$\log_{10} p_s = A - B/T$$

where units are (Kg/cm^2) for p_s and (K) for T. The values of constant A and B are given as follows:

$A = 5.97780$, $B = 2224.4$ when $20^\circ C < T < 100^\circ C$
$A = 5.64850$, $B = 2101.1$ when $100^\circ C < T < 200$ C
$A = 5.45142$, $B = 2010.8$ when $200^\circ C < T < 350^\circ C$

(2) Input Variable:

TWB temperature of gaseous phase

(3) Output Variable:

WICPWB saturation pressure for water vapor

(4) Usage:

WICPWB (TWB)

FUNCTION WICNEW

(1) Description:

Function WICNEW is used to estimate the new trial value in the iteration procedure. Figure A.3.2. shows how to determine the new trial value.

(2) Input Variables:

X1	first trial value
Y1	calculated value corresponds to X1
X2	second trial value
Y2	calculated value corresponds to X2

(3) Output Variable:

WICNEW new trial value

(4) Usage:

WICNEW (X1, Y1, X2, Y2)

FUNCTION WICTAN

(1) Description:

Function WICTAN(X) is used to obtain the ratio of SINE(X) to COSINE(X), that is, TAN(X).

(2) Input Variable:

X	angle

(3) Output Variable:

WICTAN	value of TAN (X)

(4) Usage:

WICTAN(X)

FUNCTION WICBPT

(1) Description:

Function WICBPT calculates the temperature at boiling point.

(2) Input Variables:

TSTAG	temperature
PSTAGE	pressure

(3) Output Variable:

WICBPT	temperature at boiling point

(4) Usage:

WICBPT (TSTAG, PSTAG)

AD-A114 850 PURDUE UNIV LAFAYETTE IN SCHOOL OF MECHANICAL ENGINEERING F/G 21/5
EFFECT OF WATER ON AXIAL FLOW COMPRESSORS. PART I. ANALYSIS AND--ETC(U)
JUN 81 T TSUCHIYA, S N MURTHY F33615-78-C-2401
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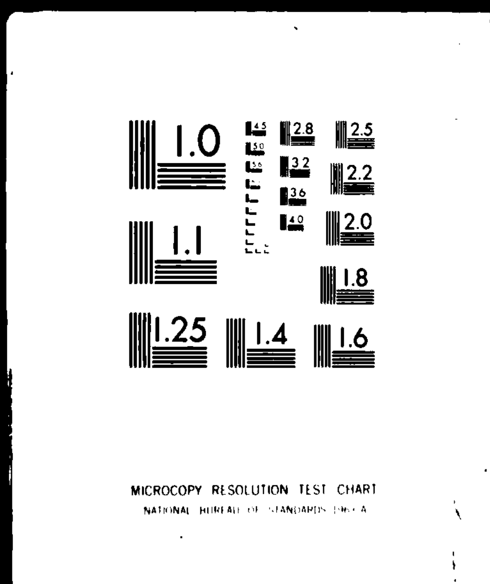

FUNCTION WICSH

(1) Description

Function WICSH calculates the specific humidity.

(2) Input Variables:

TSTAGE	temperature
PSTAG	pressure

(3) Output Variable:

WICSH	specific humidity

(4) Usage:

WICSH (TSTAG, PSTAG)

SUBROUTINE WICSIZ

(1) Description:

Subroutine WICSIZ is called at outlet of rotor and stator to determine the nominal droplet sizes. It is assumed that two kinds of droplets exist at inlet of compressor; namely, small droplet and large droplet. However, at trailing edge of each blade, the new droplets are re-entrained into blade wake. The droplets which are larger than DLIMIT are treated as large droplets and droplets which are smaller than DLIMIT are treated as small droplets. Each droplet size weighted based on its mass fraction in determining the nominal droplet size. Therefore, at outlet of each blade row, Subroutine WICSIZ gives two nominal diameters; one for small droplet and one for large droplet. It may be noted that only two classes of droplets are recognized in the model.

(2) Input Variables:

WMASSL	mass flow rate of large droplet
WMASSS	mass flow rate of small droplet
AMING1	amount of water which is to be re-entrained into wake, originally small droplet
AMING2	amount of water which is to be re-entrained into wake, originally large droplet and upper part
AMING3	amount of water which is to be re-entrained into wake, originally large droplet and lower part
DL	droplet nominal size for large droplet before impingement
DS	droplet nominal size for small droplet before impingement
D1	droplet size associated with AMING1
D2	droplet size associated with AMING2
D3	droplet size associated with AMING3
DLIMIT	largest droplet diameter which can be treated as small droplet

(3) Output Variables:

AMSLL	mass flow rate of small droplet after re-entrainment
AMLGE	mass flow rate of large droplet after re-entrainment
DSLL	droplet nominal size for small droplet
DLGE	droplet nominal size for large droplet

(4) Usage:

```
CALL WICSIZ (WMASSL, WMASSS, AMING1, AMING2, AMING3, DL, DS,
            D1, D2, D3, DLIMIT, AMSLL, AMLGE, DSLL, DLGE)
```

SUBROUTINE WICPRP

(1) Description:

Subroutine WICPRP determines the flow properties such as gas constant specific, heat ratio, and specific heat at constant pressure for the gaseous mixture. The working equations are as follows:

$$R_{mix} = x_a . R_a + x_v . R_v + x_c . R_c$$

$$c_{pmix} = x_a \cdot c_{pa} + x_v \cdot c_{pv} + x_c \cdot c_{pc}$$

$$\gamma_{mix} = \left(1.0 - \frac{R_{mix}}{c_{pmix} J}\right)^{-1}$$

where

x_a = mass fraction of air in gaseous mixture

x_v = mass fraction of water vapor in gaseous mixture

x_c = mass fraction of methane in gaseous mixture

$x_a + x_v + x_c = 1$

R_a = gas constant of air

R_v = gas constant of water v...

R_c = gas constant of methane

R_{mix} = gas constant of mixture

c_{pa} = specific heat constant pressure for air

c_{pv} = specific heat constant pressure for water vapor

c_{pc} = specific heat at constant pressure for methane

c_{pmix} = specific heat at constant pressure for mixture

r_{mix} = specific heat ratio for mixture

(2) Input Variables:

XAIR	mass fraction of air in gaseous mixture
XH2O	mass fraction of water vapor in gaseous mixture
XCH4	mass fraction of methane in gaseous mixture
T	temperature of gaseous mixture

(3) Output Variables:

RMIX	gas constant of gaseous mixture
CPMIX	specific heat constant pressure for gaseous mixture
GAMMA	specific heat ratio of gaseous mixture
G1	value for GAMMA/ (GAMMA - 1.0)
G2	value for (GAMMA - 1.0)/2.0
G3	value for -1.0/(GAMMA - 1.0)

(4) Usage:

```
CALL WICPRP (XAIR, XH2O, XCH4, T, RMIX, CPMIX, GAMMA, G1,
             G2, G3)
```

FUNCTION WICCPA

(1) Description

Function WICCPA calculates the specific heat at constant pressure for air as a function of temperature as follows: (Reference 29)

$$c_p = (a + aT = cT^2 + dt^3 + eT^4)R$$

where units are (J/kg-K) for c_p, (K) for T, and (J/kg-K) for R. The values of coefficients a, b, c, d, and e are as follows:

$a = 3.65359$

$b = -1.33736 \times 10^{-10}$

$c = 3.29421 \times 10^{-6}$

$d = -1.91142 \times 10^{-9}$

$e = 0.275462 \times 10^{-12}$

(2) Input Variable:

T temperature

(3) Output Variable:

WICCPH specific heat constant pressure

(4) Usage:

WICCPH (T)

FUNCTION WICCPH

(1) Description:

Function WICCPH calculates the specific heat at constant pressure for water vapor as a function of temperature as follows: (Reference 29)

$$c_p = (a + bT + cT^2 + dT^3 + eT^4)R$$

where units are (J/kg-K) for c_p, (K) for T, and (J/kg-K) for R. The values of coefficients a, b, c, d, and e are as follows:

$a = 4.07013$

$b = -1.10845 \times 10^{-3}$

$c = 4.15212 \times 10^{-6}$

$d = -2.96374 \times 10^{-9}$

$e = 0.807021 \times 10^{-12}$

(2) Input Variable:

T temperature

(3) Output Variable:

WICCPH specific heat at constant pressure

(4) Usage:

WICCPH (T)

FUNCTION WICCPC

(1) Description:

Function WICCPC calculates the specific heat at constant pressure for methane as a function of temperature as follows: *(Reference 29)*

$$c_p = (a + bT + cT^2 + dT^3 + eT^4)R$$

where units are (J/kg-k) for c_p, (K) for T, and (J/kg-K) for R. The values of coefficients a,b,c,d, and e are as follows:

$a = 3.82619$

$b = -3.97946 \times 10^{-3}$

$c = 24.5583 \times 10^{-6}$

$d = -22.7329 \times 10^{-9}$

$e = 6.92760 \times 10^{-12}$

(2) Input Variable:

T temperature

(3) Output Variable:

WICCPC specific heat constant pressure

(4) Usage:

WICCPC (T)

APPENDIX 4

PROGRAM SOURCE LIST

```
      PROGRAM MAIN(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)                MAIN
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ MAIN
C PROGRAM PURDU-WICSTK                                                   MAIN
C++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++  MAIN
C ABSTRACT:                                                              MAIN
C THIS PROGRAM CODE HAS BEEN PRODUCED FOR THE STUDY OF THE AXIAL FLOW    MAIN
C COMPRESSOR PERFORMANCE FOR THE GAS-WATER DROPLET MIXTURE FLOW.         MAIN
C THE MIXTURE CONSISTES OF TWO TYPES OF DROPLET SIZES AND THREE          MAIN
C KINDS OF GASEOUS PHASES.THIS PROGRAM CODE IS WRITTEN ESPECIALLY        MAIN
C FOR AIR+WATER VAPOR+METHANE+SMALL DROPLET+LARGE DROPLET.               MAIN
C THIS FORTRAN COMPUTER CODE CAN PREDICT THE DESIGN AND OFF-DESIGN       MAIN
C PERFORMANCE OF AXIAL FLOW COMPRESSOR.  STAGE AND OVERALL PERFORMANCE   MAIN
C ARE OBTAINED BY A STAGE-BY-STAGE CALCULATION.                          MAIN
C THIS COMPUTER PROGRAM CADE HAS BEEN DEVELOPED AT PURDUE UNIVERSITY,    MAIN
C THERMAL SCIENCE AND PROPULSION CENTER,WEST LAFAYETTE,INDIANA 47906,    MAIN
C UNDER AIR FORCE CONTRACT F33615-78-C-2401,PRINCIPAL INVESTIGATOR:DR.   MAIN
C S.N.B.MURTHY. THE AUTHER OF THIS PROGRAM CODE IS TOSHIAKI TSUCHIYA,    MAIN
C PURDUE UNIVERSITY , DEPARTMENT OF AERONAUTICS AND ASTRONAUTICS,        MAIN
C GRADUATE INSTRICTOR IN RESEARCH.                                       MAIN
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++  MAIN
C++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++  MAIN
      REAL ND,NU,KA,M,MMASS,MMASS1                                       MAIN
      REAL MMASS0                                                        MAIN
      COMMON TD(7),IUNIT                                                 MAIN
      COMMON CFL,CFT,CFP,CFD,CFM,CFV,CFA                                 MAIN
      COMMON JPERFM,RHOG(3),RERUP,RERLOW,RESUP,RESLOW                    MAIN
      COMMON PREB,RRTIP(8),SRTIP(8),AAA1,AAA2,AAA3,SAREA(6),SAREAS(7)    MAIN
      COMMON P(3),TG(3),XA,XV(3),XCH4,XW(3),XWW(3),XWT(3),TW(3),TWW(3)   MAIN
      COMMON OMEGS(7),OMEGR(6),GAPR(6),GAPS(6)                           MAIN
      COMMON RRHUB(6) , RC(6) , RBLADE(6) , STAGER(6)                    MAIN
      COMMON SRHUB(7) , SC(7) , SBLADE(7),STAGES(7)                      MAIN
      COMMON SIGUMR(6) , BET1SR(6) , BET2SR(6) , AINCSR(6) , ADEVSR(6)   MAIN
      COMMON SIGUMS(7) , BET1SS(7) , BET2SS(7) , AINCSS(7) , ADEVSS(7)   MAIN
      COMMON UTIPG(6),UTIP(6),UTIPD(6),UDU(6),UMEAN(6),UHUB(6),U(6),FAI  MAIN
      COMMON AREA(6),AREAS(7),UU2(6),UTIP2(6),UMEAN2(6),UHUB2(6),IPRINT  MAIN
      COMMON ICENT,IICENT,FMR1(6),FMA2(6),IDESIN,FAID                    MAIN
      COMMON NS,NS1,RT(6),RM(6),RH(6),ST(6),SM(6),SH(6)                  MAIN
      COMMON DSMASS,AAREA(7),AAREAS(7),PR12D(6),PR13D(6),ETARD(6)        MAIN
      COMMON DR(6),DS(6),DEQR(6),DEQS(6),BLOCK(6),BLOCKS(7)              MAIN
      COMMON BET1MR(6),BET2MR(6),BET1MS(7),BET2MS(7),RADI1(6),RADI2(6)   MAIN
      DIMENSION D(20,3) , XD(20,3) , XXD(20,3)                           MAIN
      DIMENSION WS(3),WMASS(3),VMASS(3),RHOA(3),RHOM(3),TB(3)            MAIN
      DIMENSION DELZ(6),ETAA(6)                                          MAIN
      DIMENSION XXA(3),XXV(3),DAVE(20)                                   MAIN
      DIMENSION TDEW(3)                                                  MAIN
      DIMENSION DDAVE(20),WWMASS(3),WTMASS(3)                            MAIN
      DIMENSION TMASS(3),GMASS(3),XAIR(3),XMETAN(3),XGAS(3),FAISTL(6)    MAIN
      DIMENSION DELB1R(7),DELB1S(7),XG1BLD(7),XG2BLD(7),XG3BLD(7),       MAIN
     $XWBLD(7),XWWBLD(7)                                                 MAIN
C++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++  MAIN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  MAIN
C                                                                     C  MAIN
C READ IUPUT DATA                                                      C  MAIN
C                                                                     C  MAIN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  MAIN
      READ(5,99) NS                                                      MAIN
   99 FORMAT(I1)                                                         MAIN
      NS1=NS+1                                                           MAIN
      READ(5,100) (RRHUB(I),I=1,NS)                                      MAIN
  100 FORMAT (6F5.3)                                                     MAIN
      READ(5,111)(RC(I),I=1,NS)                                          MAIN
  111 FORMAT(6F5.3)                                                      MAIN
      READ(5,112) (RBLADE(I),I=1,NS)                                     MAIN
  112 FORMAT(6F5.2)                                                      MAIN
      READ(5,113)(STAGER(I) ,I=1,NS)                                     MAIN
  113 FORMAT(6F5.2)                                                      MAIN
      READ(5,114)(SRHUB(I),I=1,7)                                        MAIN
  114 FORMAT(7F5.3)                                                      MAIN
      READ(5,115) (SC(I),I=1,7)                                          MAIN
  115 FORMAT(7F5.3)                                                      MAIN
```

```
      READ(5,116)(SBLADE(I),I=1,7)                                      MAIN
  116 FORMAT(7F5.2)                                                     MAIN
      READ(5,117)(SIGUMR(I),I=1,NS)                                     MAIN
  117 FORMAT(6F5.3)                                                     MAIN
      READ(5,122)(SIGUMS(I) ,I=1,NS1)                                   MAIN
  122 FORMAT(7F5.3)                                                     MAIN
      READ(5,127) FNF                                                   MAIN
  127 FORMAT(F8.2)                                                      MAIN
      READ(5,128) XDIN,ICENT,XDDIN,IICENT                               MAIN
  128 FORMAT(F5.3,I1,F5.3,I1)                                           MAIN
      READ(5,129) TOG,TOW,PO                                            MAIN
  129 FORMAT(3F7.2)                                                     MAIN
      READ(5,130) DIN,DDIN                                              MAIN
  130 FORMAT(2F6.1)                                                     MAIN
      READ(5,132) FND,T01D,P01D                                         MAIN
  132 FORMAT(F7.1,2F7.2)                                                MAIN
      READ(5,133) XCH4,RHUMID                                           MAIN
  133 FORMAT(F5.3,F10.5)                                                MAIN
      READ(5,134) FMWA,FMWV,FMWC                                        MAIN
  134 FORMAT(3F7.3)                                                     MAIN
      READ(5,135) PREB,DLIMIT                                           MAIN
  135 FORMAT(F5.1,F7.1)                                                 MAIN
      READ(5,140) (STAGES(I),I=1,NS1)                                   MAIN
  140 FORMAT(7F5.2)                                                     MAIN
      READ(5,141) (GAPR(I),I=1,NS)                                      MAIN
  141 FORMAT(6F7.5)                                                     MAIN
      READ(5,142) (GAPS(I),I=1,NS)                                      MAIN
  142 FORMAT(6F7.5)                                                     MAIN
      READ(5,146) (RRTIP(I),I=1,NS)                                     MAIN
  146 FORMAT(6F6.3)                                                     MAIN
      READ(5,147) (SRTIP(I),I=1,NS1)                                    MAIN
  147 FORMAT(7F6.3)                                                     MAIN
      READ(5,148) IPERFM,IUNIT                                          MAIN
  148 FORMAT(2I1)                                                       MAIN
      READ(5,1491) IRAD                                                 MAIN
 1491 FORMAT(I1)                                                        MAIN
      READ(5,1492) (RT(I),I=1,NS)                                       MAIN
 1492 FORMAT(6F5.3)                                                     MAIN
      READ(5,1493) (RM(I),I=1,NS)                                       MAIN
 1493 FORMAT(6F5.3)                                                     MAIN
      READ(5,1494) (RH(I),I=1,NS)                                       MAIN
 1494 FORMAT(6F5.3)                                                     MAIN
      READ(5,1495) (ST(I),I=1,NS)                                       MAIN
 1495 FORMAT(6F5.3)                                                     MAIN
      READ(5,1496) (SM(I),I=1,NS)                                       MAIN
 1496 FORMAT(6F5.3)                                                     MAIN
      READ(5,1497) (SH(I),I=1,NS)                                       MAIN
 1497 FORMAT(6F5.3)                                                     MAIN
      READ(5,1498) (BLOCK(I),I=1,NS)                                    MAIN
 1498 FORMAT(6F5.3)                                                     MAIN
      READ(5,1499) (BLOCKS(I),I=1,NS1)                                  MAIN
 1499 FORMAT(7F5.3)                                                     MAIN
      READ(5,1502) (BET1MR(I),I=1,NS)                                   MAIN
 1502 FORMAT(6F5.2)                                                     MAIN
      READ(5,1503) (BET2MR(I),I=1,NS)                                   MAIN
 1503 FORMAT(6F5.2)                                                     MAIN
      READ(5,1504) (BET1MS(I),I=1,NS1)                                  MAIN
 1504 FORMAT(7F5.2)                                                     MAIN
      READ(5,1505) (BET2MS(I),I=1,NS1)                                  MAIN
 1505 FORMAT(7F5.2)                                                     MAIN
      READ(5,1506) DSMASS                                               MAIN
 1506 FORMAT(F10.6)                                                     MAIN
      READ(5,1507) (PR12D(I),I=1,NS)                                    MAIN
 1507 FORMAT(6F5.3)                                                     MAIN
      READ(5,1508) (PR13D(I),I=1,NS)                                    MAIN
 1508 FORMAT(6F5.3)                                                     MAIN
      READ(5,1509) (ETARD(I),I=1,NS)                                    MAIN
 1509 FORMAT(6F5.3)                                                     MAIN
      READ(5,1511) (SAREA(I),I=1,NS)                                    MAIN
 1511 FORMAT(6F10.7)                                                    MAIN
```

```
      READ(5,1512) (SAREAS(I),I=1,NS1)                      MAIN
 1512 FORMAT(7F10.7)                                        MAIN
      READ(5,1513) (DELB1R(I),I=1,NS)                       MAIN
 1513 FORMAT(6F5.2)                                         MAIN
      READ(5,1514) (DELB1S(I),I=1,NS1)                      MAIN
 1514 FORMAT(7F5.2)                                         MAIN
      READ(5,1515) (XG1BLD(I),I=1,NS)                       MAIN
 1515 FORMAT(6F5.2)                                         MAIN
      READ(5,1516) (XG2BLD(I),I=1,NS)                       MAIN
 1516 FORMAT(6F5.2)                                         MAIN
      READ(5,1517) (XG3BLD(I),I=1,NS)                       MAIN
 1517 FORMAT(6F5.2)                                         MAIN
      READ(5,1518) (XWBLD(I),I=1,NS)                        MAIN
 1518 FORMAT(6F5.2)                                         MAIN
      READ(5,1519) (XWWBLD(I),I=1,NS)                       MAIN
 1519 FORMAT(6F5.2)                                         MAIN
      READ(5,1520) (BET2SS(I),I=1,NS1)                      MAIN
 1520 FORMAT(7F5.2)                                         MAIN
      CFL=2.54                                              MAIN
      CFT=1.0/1.8                                           MAIN
      CFP=47.880258                                         MAIN
      CFD=16.018463                                         MAIN
      CFM=0.45359237                                        MAIN
      CFV=0.3048                                            MAIN
      CFA=0.09290304                                        MAIN
      IF(IUNIT.NE.3) GO TO 850                              MAIN
      DO 1560 I=1,NS                                        MAIN
      RRHUB(I)=RRHUB(I)*CFL                                 MAIN
      RC(I)=RC(I)*CFL                                       MAIN
      GAPR(I)=GAPR(I)*CFL                                   MAIN
      GAPS(I)=GAPS(I)*CFL                                   MAIN
      RRTIP(I)=RRTIP(I)*CFL                                 MAIN
      RT(I)=RT(I)*CFL                                       MAIN
      RM(I)=RM(I)*CFL                                       MAIN
      RH(I)=RH(I)*CFL                                       MAIN
      ST(I)=ST(I)*CFL                                       MAIN
      SM(I)=SM(I)*CFL                                       MAIN
      SH(I)=SH(I)*CFL                                       MAIN
      SAREA(I)=SAREA(I)*CFA                                 MAIN
 1560 CONTINUE                                              MAIN
      DO 1570 I=1,NS1                                       MAIN
      SRHUB(I)=SRHUB(I)*CFL                                 MAIN
      SC(I)=SC(I)*CFL                                       MAIN
      SRTIP(I)=SRTIP(I)*CFL                                 MAIN
      SAREAS(I)=SAREAS(I)*CFA                               MAIN
 1570 CONTINUE                                              MAIN
      TOG=TOG*CFT                                           MAIN
      TOW=TOW*CFT                                           MAIN
      P0=P0*CFP                                             MAIN
      T01D=T01D*CFT                                         MAIN
      P01D=P01D*CFP                                         MAIN
      DSMASS=DSMASS*CFM                                     MAIN
      IUNIT=2                                               MAIN
  850 CONTINUE                                              MAIN
      IF(IUNIT.NE.4) GO TO 851                              MAIN
      DO 1561 I=1,NS                                        MAIN
      RRHUB(I)=RRHUB(I)/CFL                                 MAIN
      RC(I)=RC(I)/CFL                                       MAIN
      GAPR(I)=GAPR(I)/CFL                                   MAIN
      GAPS(I)=GAPS(I)/CFL                                   MAIN
      RRTIP(I)=RRTIP(I)/CFL                                 MAIN
      RT(I)=RT(I)/CFL                                       MAIN
      RM(I)=RM(I)/CFL                                       MAIN
      RH(I)=RH(I)/CFL                                       MAIN
      ST(I)=ST(I)/CFL                                       MAIN
      SM(I)=SM(I)/CFL                                       MAIN
      SH(I)=SH(I)/CFL                                       MAIN
      SAREA(I)=SAREA(I)/CFA                                 MAIN
 1561 CONTINUE                                              MAIN
      DO 1571 I=1,NS1                                       MAIN
```

```
      SRHUB(I)=SRHUB(I)/CFL
      SC(I)=SC(I)/CFL
      SRTIP(I)=SRTIP(I)/CFL
      SAREAS(I)=SAREAS(I)/CFA
 1571 CONTINUE
      TOG=TOG/CFT
      TOW=TOW/CFT
      P0=P0/CFP
      T01D=T01D/CFT
      P01D=P01D/CFP
      DSMASS=DSMASS/CFM
      IUNIT=1
  851 CONTINUE
      FNFN=FNF*100.0
      CRPM=FNF*FND
      IF(IUNIT.EQ.1) FN=FND*FNF*SQRT(TOG/518.7)
      IF(IUNIT.EQ.2) FN=FND*FNF*SQRT(TOG/288.17)
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                    C
C PRINT OUT OF INPUT DATA                                            C
C                                                                    C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      WRITE(6,1600)
 1600 FORMAT(1H1,5X,≠****************************** INPUT DATA **********
     $***************************≠)
      WRITE(6,1610) NS
 1610 FORMAT(1H0,1X,≠NS(NUMBER OF STAGE)=≠,I2)
      IF(IUNIT.EQ.1) WRITE(6,1601)
 1601 FORMAT(1H ,1X,≠UNIT=ENGLISH UNIT≠)
      IF(IUNIT.EQ.2) WRITE(6,1602)
 1602 FORMAT(1H ,1X,≠UNIT=METRIC UNIT≠)
      WRITE(6,1603) IPERFM
 1603 FORMAT(1H ,1X,≠IPERFM=≠,I1)
      IF(IRAD.EQ.1) WRITE(6,1604)
 1604 FORMAT(1H ,1X,≠PERFORMANCE AT TIP≠)
      IF(IRAD.EQ.2) WRITE(6,1605)
 1605 FORMAT(1H ,1X,≠PERFORMANCE AT MEAN≠)
      IF(IRAD.EQ.3) WRITE(6,1606)
 1606 FORMAT(1H ,1X,≠PERFORMANCE AT HUB≠)
      WRITE(6,1620)
 1620 FORMAT(1H0,14X,≠1≠,5X,≠2≠,5X,≠3≠,5X,≠4≠,5X,≠5≠,5X,≠6≠,4X,≠IGV≠)
      WRITE(6,1630) (RRHUB(I),I=1,NS)
 1630 FORMAT(1H ,1X,≠RRHUB(I)≠,3X,6(F5.3,1X))
      WRITE(6,1640) (RC(I),I=1,NS)
 1640 FORMAT(1H ,1X,≠RC(I)≠,6X,6(F5.3,1X))
      WRITE(6,1650) (RBLADE(I),I=1,NS)
 1650 FORMAT(1H ,1X,≠RBLADE(I)≠,2X,6(F5.2,1X))
      WRITE(6,1660) (STAGER(I),I=1,NS)
 1660 FORMAT(1H ,1X,≠STAGER(I)≠,2X,6(F5.2,1X))
      WRITE(6,1661) (STAGES(I),I=1,NS)
 1661 FORMAT(1H ,1X,≠STAGES(I)≠,2X,6(F5.2,1X))
      WRITE(6,1670) (SRHUB(I),I=1,NS1)
 1670 FORMAT(1H ,1X,≠SRHUB(I)≠,3X,7(F5.3,1X))
      WRITE(6,1680) (SC(I),I=1,NS)
 1680 FORMAT(1H ,1X,≠SC(I)≠,6X,6(F5.3,1X))
      WRITE(6,1690) (SBLADE(I),I=1,NS)
 1690 FORMAT(1H ,1X,≠SBLADE(I)≠,2X,6(F5.2,1X))
      WRITE(6,1700) (SIGUMR(I),I=1,NS)
 1700 FORMAT(1H ,1X,≠SIGUMR(I)≠,2X,6(F5.3,1X))
      WRITE(6,1750) (SIGUMS(I),I=1,NS)
 1750 FORMAT(1H ,1X,≠SIGUMS(I)≠,2X,6(F5.3,1X))
      WRITE(6,1795) (GAPR(I),I=1,NS)
 1795 FORMAT(1H ,1X,≠GAPR(I ≠,4X,6(F5.3,1X))
      WRITE(6,1796) (GAPS(I),I=1,NS)
 1796 FORMAT(1H ,1X,≠GAPS(I)≠,4X,6(F5.3,1X))
      WRITE(6,1798) (RRTIP(I),I=1,NS)
 1798 FORMAT(1H ,1X,≠RRTIP(I)≠,3X,6(F5.2,1X))
      WRITE(6,1799) (SRTIP(I),I=1,NS1)
 1799 FORMAT(1H ,1X,≠SRTIP(I)≠,3X,7(F5.2,1X))
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      WRITE(6,1801) (RT(I),I=1,NS)
 1801 FORMAT(1H ,1X,≠RT(I)≠,6X,6(F5.3,1X))
      WRITE(6,1802) (RM(I),I=1,NS)
 1802 FORMAT(1H ,1X,≠RM(I)≠,6X,6(F5.3,1X))
      WRITE(6,1803) (RH(I),I=1,NS)
 1803 FORMAT(1H ,1X,≠RH(I)≠,6X,6(F5.3,1X))
      WRITE(6,1804) (ST(I),I=1,NS)
 1804 FORMAT(1H ,1X,≠SH(I)≠,6X,6(F5.3,1X))
      WRITE(6,1805) (SM(I),I=1,NS)
 1805 FORMAT(1H ,1X,≠SM(I)≠,6X,6(F5.3,1X))
      WRITE(6,1806) (SH(I),I=1,NS)
 1806 FORMAT(1H ,1X,≠SH(I)≠,6X,6(F5.3,1X))
      WRITE(6,1807) (BLOCK(I),I=1,NS)
 1807 FORMAT(1H ,1X,≠BLOCK(I)≠,3X,6(F5.3,1X))
      WRITE(6,1808) (BLOCKS(I),I=1,NS)
 1808 FORMAT(1H ,1X,≠BLOCKS(I)≠,2X,6(F5.3,1X))
      WRITE(6,1811) (BET1MR(I),I=1,NS)
 1811 FORMAT(1H ,1X,≠BET1MR(I)≠,2X,6(F5.2,1X))
      WRITE(6,1812) (BET2MR(I),I=1,NS)
 1812 FORMAT(1H ,1X,≠BET2MR(I)≠,2X,6(F5.2,1X))
      WRITE(6,1813) (BET1MS(I),I=1,NS1)
 1813 FORMAT(1H ,1X,≠BET1MS(I)≠,2X,7(F5.2,1X))
      WRITE(6,1814) (BET2MS(I),I=1,NS1)
 1814 FORMAT(1H ,1X,≠BET2MS(I)≠,2X,7(F5.2,1X))
      WRITE(6,1815) (PR12D(I),I=1,NS)
 1815 FORMAT(1H ,1X,≠PR12D(I)≠,3X,6(F5.3,1X))
      WRITE(6,1816) (PR13D(I),I=1,NS)
 1816 FORMAT(1H ,1X,≠PR13D(I)≠,3X,6(F5.3,1X))
      WRITE(6,1817) (ETARD(I),I=1,NS)
 1817 FORMAT(1H ,1X,≠ETARD(I)≠,3X,6(F5.3,1X))
      WRITE(6,1818)
 1818 FORMAT(1H1,5X,≠****************************** INPUT DATA **********
     $********************≠)
      WRITE(6,1800) FNF
 1800 FORMAT(1H0,1X,≠FNF(FRACTION OF DESIGN CORRECTED SPEED)=≠,F5.3)
      WRITE(6,1810) XDIN,XDDIN,RHUMID,XCH4
 1810 FORMAT(1H0,1X,≠XDIN(INITIAL WATER CONTENT OF SMALL DROPLET)=≠,F5.3
     $,/,2X,≠XDDIN(INITIAL WATER CONTENT OF LARGE DROPLET)=≠,F5.3,/,
     $2X,≠RHUMID(INITIAL RELATIVE HUMIDITY)=≠,F6.2,1X,≠PER CENT≠,/,
     $2X,≠XCH4(INITIAL METHANE CONTENT)=≠,F5.3)
      WRITE(6,1820) TOG,TOW,PO
 1820 FORMAT(1H0,1X,≠TOG(COMPRESSOR INLET TOTAL TEMPRATURE OF GAS)=≠,
     $F7.2,/,2X,≠TOW(COMPRESSOR INLET TEMPERATURE OF DROPLRET)=≠,F7.2,/,
     $2X,≠PO(COMPRESSOR INLET TOTAL PRESSURE)=≠,F10.2)
      WRITE(6,1830) DIN,DDIN
 1830 FORMAT(1H0,1X,≠DIN(INITIIL DROPLET DIAMETER OF SMALL DROPLET)=≠,
     $F6.1,/,2X,≠DDIN(INITIAL DROPLET DIAMETER OF LARGE DROPLET)=≠,F6.1)
      WRITE(6,1850) FND
 1850 FORMAT(1H0,1X,≠FND(DESIGN ROTATIONAL SPEED)=≠,F7.1)
      WRITE(6,1851) DSMASS
 1851 FORMAT(1H0,1X,≠DSMASS(DESIGN MASS FLOW RATE)=≠,F10.4)
      WRITE(6,1860) TOG
 1860 FORMAT(1H0,1X,≠COMPRESSOR INLET TATAL TEMPERATURE(GAS PHASE)≠ ,
     $F7.2)
      WRITE(6,1870) PO
 1870 FORMAT(1H0,1X,≠COMPRESSOR INLET TOTAL PRESSURE=≠,F10.2)
      WRITE(6,1880) PREB
 1880 FORMAT(1H0,1X,≠PREB(PERCENT OF WATER THAT REBOUND AFTER IMPINGE
     $MENT)=≠,F5.1,1X,≠PERCENT≠)
      WRITE(6,1900) FN
 1900 FORMAT(1H0,1X,≠ROTOR SPEED=≠,F7.1,1X,≠RPM≠)
      WRITE(6,1910) CRPM,FNFN
 1910 FORMAT(1H0,1X,≠CORRECTED ROTOR SPEED= ≠,F7.1,1X,≠RPM≠,≠(≠,2X,F5.1,
     $≠PER CENT OF DESIGN CORRECTED SPEED)≠)
      IF(IUNIT.NE.2) GO TO 852
      DO 156 I=1,NS
      RRHUB(I)=RRHUB(I)/CFL
      RC(I)=RC(I)/CFL
      GAPR(I)=GAPR(I)/CFL
      GAPS(I)=GAPS(I)/CFL
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      RRTIP(I)=RRTIP(I)/CFL
      RT(I)=RT(I)/CFL
      RM(I)=RM(I)/CFL
      RH(I)=RH(I)/CFL
      ST(I)=ST(I)/CFL
      SM(I)=SM(I)/CFL
      SH(I)=SH(I)/CFL
      SAREA(I)=SAREA(I)/CFA
  156 CONTINUE
      DO 157 I=1,NS1
      SRHUB(I)=SRHUB(I)/CFL
      SC(I)=SC(I)/CFL
      SRTIP(I)=SRTIP(I)/CFL
      SAREAS(I)=SAREAS(I)/CFA
  157 CONTINUE
      TOG=TOG/CFT
      TOW=TOW/CFT
      P0=P0/CFP
      T01D=T01D/CFT
      P01D=P01D/CFP
      DSMASS=DSMASS/CFM
  852 CONTINUE
C++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C OTHER INPUT DATA
      WKDONE=1.0
      IPRINT=1
      DO 153 I=1,NS
      FMR1(I)=0.6
      FMA2(I)=0.6
  153 CONTINUE
      AK1=1.0
      AK2=1.0
      AK3=1.0
      AAAIGV=SAREA(1)
      RU=1545.3
      RHOW=62.54
      CPW=1.00
      RA=RU/FMWA
      RV=RU/FMWV
      RCH=RU/FMWC
      DELV=0.0
      DELVU2=10.0
      DELVL2=10.0
      GC=32.174
      AJ=778.16
      PAI=3.1415926
      DO 150 I=1,NS
      AAREA(I)=PAI*((RRTIP(I)/12.0)**2-(RRHUB(I)/12.0)**2)*BLOCK(I)
      AAREAS(I)=PAI*(SRTIP(I)**2-SRHUB(I)**2)/144.0*BLOCKS(I)
      DELZ(I)=(RC(I)+SC(I))/12.0
  150 CONTINUE
      NS1=NS+1
      AAREAS(NS1)=PAI*(SRTIP(NS1)**2-SRHUB(NS1)**2)/144.0*BLOCKS(NS1)
      AAAR1T=AAREA(1)
       DO 152 I=1,NS
      AREA(I)=SAREA(I)
      AREAS(I)=SAREAS(I)
  152 CONTINUE
      AREAS(NS1)=SAREAS(NS1)
      OT01G=TOG
      OT01D=TOW
      OP01=P0
      DO 151 I=1,NS
      UTIP(I)=RT(I)/12.0*2.0*PAI*FND/60.0
      UTIPG(I)=RRTIP(I)/12.0*2.0*PAI*FND/60.0
      UTIP2(I)=ST(I)/12.0*2.0*PAI*FND/60.0
      UTIPD(I)=RT(I)/12.0*2.0*PAI*FND/60.0
      UOU(I)=(UTIP(I)/UTIPD(I))**2
      UMEAN(I)=RM(I)/12.0*2.0*PAI*FND/60.0
      UMEAN2(I)=SM(I)/12.0*2.0*PAI*FND/60.0
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```
      UHUB(I)=RH(I)/12.0*2.0*PAI*FND/60.0                              MAIN
      UHUB2(I)=SH(I)/12.0*2.0*PAI*FND/60.0                             MAIN
      IF(IRAD.EQ.1) U(I)=UTIP(I)                                        MAIN
      IF(IRAD.EQ.2) U(I)=UMEAN(I)                                       MAIN
      IF(IRAD.EQ.3) U(I)=UHUB(I)                                        MAIN
      IF(IRAD.EQ.1) UU2(I)=UTIP2(I)                                     MAIN
      IF(IRAD.EQ.2) UU2(I)=UMEAN2(I)                                    MAIN
      IF(IRAD.EQ.3) UU2(I)=UHUB2(I)                                     MAIN
      IF(IRAD.EQ.1) RADI1(I)=RT(I)                                      MAIN
      IF(IRAD.EQ.1) RADI2(I)=ST(I)                                      MAIN
      IF(IRAD.EQ.2) RADI1(I)=RM(I)                                      MAIN
      IF(IRAD.EQ.2) RADI2(I)=SM(I)                                      MAIN
      IF(IRAD.EQ.3) RADI1(I)=RH(I)                                      MAIN
      IF(IRAD.EQ.3) RADI2(I)=SH(I)                                      MAIN
  151 CONTINUE                                                          MAIN
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ MAIN
C BLADE RESETTING                                                       MAIN
      DO 154 I=1,NS                                                     MAIN
      BET1MR(I)=BET1MR(I)+DELB1R(I)                                     MAIN
      BET2MR(I)=BET2MR(I)+DELB1R(I)                                     MAIN
      STAGER(I)=STAGER(I)+DELB1R(I)                                     MAIN
      BET1MS(I)=BET1MS(I)+DELB1S(I)                                     MAIN
      BET2MS(I)=BET2MS(I)+DELB1S(I)                                     MAIN
      STAGES(I)=STAGES(I)+DELB1S(I)                                     MAIN
  154 CONTINUE                                                          MAIN
      TG(1)=T01D                                                        MAIN
      P(1)=P01D                                                         MAIN
      CALL WICSPD(DSMASS,ISTAGE)                                        MAIN
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ MAIN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC MAIN
C                                                                      C MAIN
C ROTER SPEED AND RADIUS                                                C MAIN
C                                                                      C MAIN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC MAIN
      DO 155 I=1,NS                                                     MAIN
      UTIP(I)=RT(I)/12.0*2.0*PAI*FN/60.0                                MAIN
      UTIPG(I)=RRTIP(I)/12.0*2.0*PAI*FN/60.0                            MAIN
      UTIP2(I)=ST(I)/12.0*2.0*PAI*FN/60.0                               MAIN
      UTIPD(I)=RT(I)/12.0*2.0*PAI*FND/60.0                              MAIN
      UOU(I)=(UTIP(I)/UTIPD(I))**2                                      MAIN
      UMEAN(I)=RM(I)/12.0*2.0*PAI*FN/60.0                               MAIN
      UMEAN2(I)=SM(I)/12.0*2.0*PAI*FN/60.0                              MAIN
      UHUB(I)=RH(I)/12.0*2.0*PAI*FN/60.0                                MAIN
      UHUB2(I)=SH(I)/12.0*2.0*PAI*FN/60.0                               MAIN
      IF(IRAD.EQ.1) U(I)=UTIP(I)                                        MAIN
      IF(IRAD.EQ.2) U(I)=UMEAN(I)                                       MAIN
      IF(IRAD.EQ.3) U(I)=UHUB(I)                                        MAIN
      IF(IRAD.EQ.1) UU2(I)=UTIP2(I)                                     MAIN
      IF(IRAD.EQ.2) UU2(I)=UMEAN2(I)                                    MAIN
      IF(IRAD.EQ.3) UU2(I)=UHUB2(I)                                     MAIN
      IF(IRAD.EQ.1) RADI1(I)=RT(I)                                      MAIN
      IF(IRAD.EQ.1) RADI2(I)=ST(I)                                      MAIN
      IF(IRAD.EQ.2) RADI1(I)=RM(I)                                      MAIN
      IF(IRAD.EQ.2) RADI2(I)=SM(I)                                      MAIN
      IF(IRAD.EQ.3) RADI1(I)=RH(I)                                      MAIN
      IF(IRAD.EQ.3) RADI2(I)=SH(I)                                      MAIN
  155 CONTINUE                                                          MAIN
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ MAIN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC MAIN
C                                                                      C MAIN
C MASS FLOE RATE                                                        C MAIN
C                                                                      C MAIN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC MAIN
  901 READ(5,200) FAI                                                   MAIN
  200 FORMAT(F7.5)                                                      MAIN
      ISTAGE=0                                                          MAIN
      N=1                                                               MAIN
      IF(FAI.GT.1.0) GO TO 998                                          MAIN
      IF(IPRINT.EQ.2) WRITE(6,197) FAI                                  MAIN
  197 FORMAT(1H1,2X,≠FAI=≠,F7.5)                                        MAIN
```

```
      FAIO=FAI
      VZ=UTIPG(1)*FAI
      TG(1)=OT01G
      UZERO=0.0
      UUZERO=0.0
      RZERO=RRHUB(1)
      RRZERO=RRHUB(1)
      ITIP=0
      IITIP=0
      DAVE(N)=0.0
      DDAVE(N)=0.0
      TW(1)=OT01D
      TWW(1)=OT01D
      IF(XDIN.GT.0.0) DAVE(N)=DIN
      IF(XDDIN.GT.0.0) DDAVE(N)=DDIN
      IF(XDIN.GT.0.0) TW(1)=OT01D
      IF(XDDIN.GT.0.0) TWW(1)=OT01D
      P(1)=OP01
      TB(1) = WICBPT(TG(1), P(1))
      WS(1) = WICSH(TG(1) , P(1) )*RHUMID/100.0
      PW=WS(1)*P(1)/(WS(1)+0.6219)
      TDEW(1)=WICBPT(TG(1),PW)
      XW(1)=XDIN
      XWW(1)=XDDIN
      XWT(1)=XW(1)+XWW(1)
      XWTO=XWT(1)
      XV(1)=WS(1)/(1.0+WS(1))*(1.0-XWT(1)-XCH4)
      XA=1.0-XWT(1)-XV(1)-XCH4
      XG=XA+XV(1)+XCH4
      XAIN=XA
      XCH4IN=XCH4
      ISTAGE=1
      CALL WICPRP(XA,XV(1),XCH4,TG(1),RMIX,CPMIX,GAMMA,G1,G2,G3)
      GAMMAI=GAMMA
      RHOG(1)=P(1)/RMIX/TG(1)
      RHOA(1)=P(1)/RA/TG(1)
      AMASSM=-1.0
      AAA2=AAAIGV
      AAA3=AAAIGV
      CALL WICMAC(ISTAGE,AMASSM,TG(1),P(1),M,UZ,C,XWT(1),BET2SS(NS1),
     $RMIX,CPMIX,AAA3)
      RHOG(1)=(1.0+G2*M**2)**G3*RHOG(1)
      RHOM(1)=1.0/((1.0-XWT(1))/RHOG(1)+XWT(1)/RHOW)
      MMASS = RHOM(1)*FAI*UTIPG(1)*AAA3
      MMASSO=MMASS
      WMASSO=MMASSO*XDIN
      WWMASO=MMASSO*XDDIN
      IF(IPRINT.EQ.2) WRITE(6,5558) MMASSO,XDIN,WMASSO,MMASS
 5558 FORMAT(1H0,2X,4(F10.5,2X))
      DAMY=OT01G/518.7
      DAMY2=OP01/(14.7*144.0)
      CMASS=MMASS*SQRT(DAMY)/DAMY2
      AMASS = XA * MMASS
      WMASS(1)=XW(1)*MMASS
      WWMASS(1)=XWW(1)*MMASS
      WTMASS(1)=XWT(1)*MMASS
      VMASS(1)=XV(1)*MMASS
      CHMASS=XCH4*MMASS
      GMASS(1)=MMASS-WTMASS(1)
      CMASS2=GMASS(1)*SQRT(DAMY)/DAMY2
      AMO=AMASS
      VMO=VMASS(1)
      CMO=CHMASS
      GMO=GMASS(1)
      WMO=WMASS(1)
      WWMO=WWMASS(1)
      WTMO=WTMASS(1)
      TLMO=GMO+WTMO
      TWMAS=WMASSO*AAAR1T/AAAIGV
      TWWMAS=WWMASO*AAAR1T/AAAIGV
```

```
      WMASTL=TWMAS+TWWMAS                                                MAIN
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++            MAIN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC MAIN
C                                                                       C MAIN
C INITIAL VALUES                                                        C MAIN
C                                                                       C MAIN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC MAIN
      TG(3)=TG(1)                                                        MAIN
      TW(3)=TW(1)                                                        MAIN
      TWW(3)=TWW(1)                                                      MAIN
      P(3)=P(1)                                                          MAIN
      TB(3)=TB(1)                                                        MAIN
      WS(3)=WS(1)                                                        MAIN
      TDEW(3)=TDEW(1)                                                    MAIN
      XV(3)=XV(1)                                                        MAIN
      XG=XA+XV(3)+XCH4                                                   MAIN
      XW(3)=XW(1)                                                        MAIN
      XWW(3)=XWW(1)                                                      MAIN
      VMASS(3)=VMASS(1)                                                  MAIN
      WMASS(3)=WMASS(1)                                                  MAIN
      WWMASS(3)=WWMASS(1)                                                MAIN
      WCENT=WMASS0                                                       MAIN
      WWCENT=WWMAS0                                                      MAIN
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++  MAIN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC MAIN
C                                                                       C MAIN
C IGV                                                                   C MAIN
C                                                                       C MAIN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC MAIN
C IGV IMPINGEMENT                                                        MAIN
      CALL WICISS(7,RADI1(1), XW(1) , XG , RHOG(1),0.0,VZ,WW1,WW2,WW)    MAIN
      AMIMPS=WW                                                          MAIN
      AMWAKS = AMIMPS * (1.0-PREB)                                       MAIN
      AMREBS=AMIMPS*PREB                                                 MAIN
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++  MAIN
C IGV WAKE                                                               MAIN
      N=2                                                                MAIN
      DAVE(2)=DAVE(1)                                                    MAIN
      DDAVE(2)=DDAVE(1)                                                  MAIN
      ALFA3=BET2SS(NS1)*(FAID/FAI)**(1.0/7.0)                            MAIN
      DWAKEM=0.0                                                         MAIN
      IF(XDIN.GT.0.0.OR.XDDIN.GT.0.0) GO TO 628                          MAIN
      GO TO 629                                                          MAIN
  628 CALL WICWAK(RHOG(1),VZ,DWAKE,DWAKEM)                               MAIN
  629 CONTINUE                                                           MAIN
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++  MAIN
C IGV OUTLET                                                             MAIN
      WMASS(3) = WMASS(1)                                                MAIN
      XW(3) = XW(1)                                                      MAIN
      PRATIO=1.0                                                         MAIN
      TRATIO=1.0                                                         MAIN
      EFF=1.0                                                            MAIN
      AMIMPR=0.0                                                         MAIN
      AMREBR=0.0                                                         MAIN
      AMWAKR=0.0                                                         MAIN
      DELTGW=0.0                                                         MAIN
      DELTDW=0.0                                                         MAIN
      DELTGH=0.0                                                         MAIN
      DELTDH=0.0                                                         MAIN
      DELT=0.0                                                           MAIN
      DELP=0.0                                                           MAIN
      DMDTAV=0.0                                                         MAIN
      XV(3)=XV(1)                                                        MAIN
      XW(3)=XW(1)                                                        MAIN
      XWW(3)=XWW(1)                                                      MAIN
      WMASS(3) = WMASS(1)                                                MAIN
      WWMASS(3)=WWMASS(1)                                                MAIN
      VMASS(3) = VMASS(1)                                                MAIN
      WS(3) = WS(1)                                                      MAIN
      TDEW(3)=TDEW(1)                                                    MAIN
```

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      RHOA(3) = RHOA(1)                                                 MAIN
      RHOM(3) = RHOM(1)                                                 MAIN
      RHOG(3) = RHOG(1)                                                 MAIN
      TG(3) = TG(1)                                                     MAIN
      TW(3) = TW(1)                                                     MAIN
      TWW(3)=TWW(1)                                                     MAIN
      P(3) = P(1)                                                       MAIN
      TB(3) = TB(1)                                                     MAIN
      XV(2)=0.0                                                         MAIN
      XW(2) = 0.0                                                       MAIN
      XWW(2)=0.0                                                        MAIN
      WMASS(2) = 0.0                                                    MAIN
      WWMASS(2)=0.0                                                     MAIN
      VMASS(2) = 0.0                                                    MAIN
      WS(2) = 0.0                                                       MAIN
      RHOA(2)=0.0                                                       MAIN
      RHOM(2) = 0.0                                                     MAIN
      RHOG(2)= 0.0                                                      MAIN
      TG(2)=0.0                                                         MAIN
      TW(2) =0.0                                                        MAIN
      TWW(2)=0.0                                                        MAIN
      P(2) = 0.0                                                        MAIN
      TB(2) = 0.0                                                       MAIN
      TDEW(2)=0.0                                                       MAIN
      GAMMAO=GAMMA                                                      MAIN
      RHOG(2)=RHOG(1)                                                   MAIN
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++  MAIN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC MAIN
C                                                                      C MAIN
C ROTER INLET                                                          C MAIN
C                                                                      C MAIN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC MAIN
  900 ISTAGE=ISTAGE+1                                                   MAIN
      IF(IPRINT.EQ.2) WRITE(6,8001) FAIO,ISTAGE                         MAIN
 8001 FORMAT(1H1,1X,≠********************  ≠,1X,                        MAIN
     $≠INITIAL FLOW COEFFICIENT=≠,1X,F5.3,1X,≠(ISTAGE= ≠,I2,1X,         MAIN
     $≠)≠,2X,≠********************≠)                                    MAIN
      TG(1)=TG(3)                                                       MAIN
      TW(1)=TW(3)                                                       MAIN
      TWW(1)=TWW(3)                                                     MAIN
      P(1)=P(3)                                                         MAIN
      TB(1)=TB(3)                                                       MAIN
      RHOA(1)=P(1)/RA/TG(1)                                             MAIN
      WS(1)=WS(3)                                                       MAIN
      TDEW(1)=TDEW(3)                                                   MAIN
      XV(1)=XV(3)                                                       MAIN
      XCH4=CHMASS/MMASS                                                 MAIN
      XA=AMASS/MMASS                                                    MAIN
      XG=XA+XV(1)+XCH4                                                  MAIN
      XAIR(1)=XA                                                        MAIN
      XMETAN(1)=XCH4                                                    MAIN
      XGAS(1)=XG                                                        MAIN
      XW(1)=XW(3)                                                       MAIN
      XWW(1)=XWW(3)                                                     MAIN
      XWT(1)=XW(1)+XWW(1)                                               MAIN
      VMASS(1)=VMASS(3)                                                 MAIN
      WMASS(1)=WMASS(3)                                                 MAIN
      WWMASS(1)=WWMASS(3)                                               MAIN
      WTMASS(1)=WMASS(1)+WWMASS(1)                                      MAIN
      MMASS=AMASS+CHMASS+VMASS(1)+WTMASS(1)                             MAIN
      TMASS(1)=MMASS                                                    MAIN
      GMASS(1)=TMASS(1)-WTMASS(1)                                       MAIN
      ALFA1=ALFA3                                                       MAIN
      CALL WICPRP(XA,XV(1),XCH4,TG(1),RMIX,CPMIX,GAMMA,G1,G2,G3)        MAIN
      GAMMAS=GAMMA                                                      MAIN
      AAA1=AAA3                                                         MAIN
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++  MAIN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC MAIN
C                                                                      C MAIN
C STAGE PERFORMANCE CALCULATION                                        C MAIN
```

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C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      IF(IPERFM.EQ.1) JPERFM=1
      IF(IPERFM.EQ.2) JPERFM=2
      IF(IPERFM.EQ.3) JPERFM=3
      DAMY=0.0
      IF(WTMASS(1).GT.1.0E-4)
     $DAMY=WWMASS(1)/WTMASS(1)
      IF(DAMY.GT.0.20) JPERFM=3
      IF(IPRINT.EQ.2) WRITE(6,8000) JPERFM
 8000 FORMAT(1H0,≠ STAGE PERFORMANCE CALCULATION (JPERFM=≠,I2,≠ )≠)
      IF(JPERFM.EQ.1) GO TO 1300
      IF(JPERFM.EQ.2) GO TO 1301
      IF(JPERFM.EQ.3) GO TO 1302
 1300 CALL WICSPA(FAIO,ISTAGE,MMASS,ALFA1,WKDONE,DAVE(N),XDIN,ETA,
     $BETA1,BETA2,VZ,ALFA2,ALFA3,DELTG,DELTW,W1,W2,V1,V2,V3,AK1,AK3)
      GO TO 1303
 1301 CALL WICSPB(FAIO,ISTAGE,MMASS,ALFA1,WKDONE,DAVE(N),DELV,WMASS(1)
     $,N,OMEGA1,
     $OMRGA2,OMEGA3,OMEGA4,OMEGA5,OMEGA6,OMEGAT,BETA1,BETA2,VZ,ALFA2,
     $ALFA3,DELTG,DELTW,W1,W2,V1,V2,V3,AK1,AK2,AK3)
      GO TO 1303
 1302 CALL WICSPC(FAIO,ISTAGE,MMASS,ALFA1,WKDONE,DDAVE(N),DELV,WMASS(
     $1),WWMASS(1),N,OMEGA1
     $,OMEGA2,OMEGA3,OMEGA4,OMEGA5,OMEGA6,OMEGAT,BETA1,BETA2,VZ,ALFA2,
     $ALFA3,DELTG,DELTW,W1,W2,V1,V2,V3,REAVE,DELVU2,DELVL2,AK1,AK2,
     $AK3)
 1303 CONTINUE
      DELTG1=DELTG
      DELTW1=DELTW
      IF(VZ.LT.0.0.OR.VZ.GT.1000.0) WRITE(6,1304) VZ
 1304 FORMAT(1H0,1X,≠AXIAL VELOCITY IS TOO HIGH OR TOO LOW≠,≠VZ=≠,
     $F10.5)
      IF(VZ.LT.0.0.OR.VZ.GT.1000.0) GO TO 901
      AAA2=AREAS(ISTAGE)
      AAA3=AREA(ISTAGE+1)
      IF(ISTAGE.EQ.NS) AAA3=AAA2
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C ROTOR IMPINGEMENT                                                     C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C ROTOR IMPINGEMENT(SMALL DROPLET)
      IF(IPRINT.EQ.2) WRITE(6,8010)
 8010 FORMAT(1H1,≠ ROTOR IMPINGEMENT(SMALL DROPLET)≠)
      CALL WICIRS(ISTAGE,RADI1(ISTAGE),XW(1),XG,RHOG(1),BETA1,W1,WW1,
     $WW2,WW)
      AMIMPR=WW
      IF(AMIMPR.LT.0.0) AMIMPR=0.0
      IF(AMIMPR.GT.WMASS(1)) AMIMPR=WMASS(1)
      AMREBR=AMIMPR*PREB/100.0
      AMWAKR=AMIMPR*(1.0-PREB/100.0)
      AMNOIR=WMASS(1)-AMIMPR
      XWNOIR=AMNOIR/MMASS
      XWREBR=AMREBR/MMASS
      XWWAKR=AMWAKR/MMASS
      IF(IPRINT.EQ.2) WRITE(6,609) AMIMPR,AMREBR,AMWAKR,AMNOIR,
     $XWNOIR,XWREBR,XWWAKR
  609 FORMAT(1H ,7(F12.5,1X))
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C ROTOR IMPINGEMENT(LARGE DROPLET)
      IF(IPRINT.EQ.2) WRITE(6,8020)
 8020 FORMAT(1H0,≠ ROTOR IMPINGEMENT(LARGE DROPLET)≠)
      CALL WICIRL(ISTAGE,RADI1(ISTAGE),XWW(1),XG,RHOG(1),BETA1,W1,WW1,WW
     $2,WW)
      BMIMPR=WW
      IF(BMIMPR.LT.0.0) BMIMPR=0.0
      IF(BMIMPR.GT.WWMASS(1)) BMIMPR=WWMASS(1)
      BMREBR=BMIMPR*PREB/100.0
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      BMWAKR=BMIMPR*(1.0-PREB/100.0)                                    MAIN
      BMNOIR=WWMASS(1)-BMIMPR                                           MAIN
      XWWB=0.0                                                          MAIN
      IF(WWMASS(1).GT.1.0E-6) XWWB=BMWAKR/WWMASS(1)                     MAIN
      XWWNOR=BMNOIR/MMASS                                               MAIN
      XWWRER=BMREBR/MMASS                                               MAIN
      XWWAR=BMWAKR/MMASS                                                MAIN
      IF(IPRINT.EQ.2) WRITE(6,6090) BMIMPR,BMREBR,BMWAKR,BMNOIR,XWWNOR, MAIN
     $XWWRER,XWWAR                                                      MAIN
 6090 FORMAT(1H ,7(F12.5,1X))                                           MAIN
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++  MAIN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC MAIN
C                                                                      C MAIN
C ROTOR WAKE                                                           C MAIN
C                                                                      C MAIN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC MAIN
      IF(IPRINT.EQ.2) WRITE(6,8030)                                     MAIN
 8030 FORMAT(1H0,≠ ROTOR WAKE≠)                                         MAIN
      N=N+1                                                             MAIN
      ALFA=BETA2                                                        MAIN
      DWAKEM=0.0                                                        MAIN
      IF(AMWAKR.GT.0.0) GO TO 630                                       MAIN
      GO TO 631                                                         MAIN
  630 CALL WICWAK(RHOG(1),W2,DWAKE,DWAKEM)                              MAIN
  631 D1=DWAKEM                                                         MAIN
      IF(D1.LT.0.0) D1=0.0                                              MAIN
      IF(D1.GT.DIN) D1=DIN                                              MAIN
      AMING1=AMWAKR                                                     MAIN
      ALFA=BETA2                                                        MAIN
      RDELV1=DELVU2                                                     MAIN
      DWAKEM=0.0                                                        MAIN
      IF(BMWAKR.GT.0.0) GO TO 6310                                      MAIN
      GO TO 6311                                                        MAIN
 6310 CALL WICWAK(RHOG(1),RDELV1,DWAKE,DWAKEM)                          MAIN
 6311 D2=DWAKEM                                                         MAIN
      IF(D2.LT.0.0) D2=0.0                                              MAIN
      IF(D2.GT.DDIN) D2=DDIN                                            MAIN
      RUP2=(90.0-BETA2)/180.0                                           MAIN
      AMING2=BMWAKR*RUP2                                                MAIN
      RDELV2=DELVL2                                                     MAIN
      DWAKEM=0.0                                                        MAIN
      IF(BMWAKR.GT.0.0) GO TO 6312                                      MAIN
      GO TO 6313                                                        MAIN
 6312 CALL WICWAK(RHOG(1),RDELV2,DWAKE,DWAKEM)                          MAIN
 6313 D3=DWAKEM                                                         MAIN
      IF(D3.LT.0.0) D3=0.0                                              MAIN
      IF(D3.GT.DDIN) D3=DDIN                                            MAIN
      RLOW2=(90.0+BETA2)/180.0                                          MAIN
      AMING3=BMWAKR*RLOW2                                               MAIN
      WMASSS=WMASS(1)-AMWAKR                                            MAIN
      WMASSL=WWMASS(1)-BMWAKR                                           MAIN
      CALL WICSIZ(WMASSL,WMASSS,AMING1,AMING2,AMING3,DDAVE(1            MAIN
     $),DAVE(1),D1,D2,D3,DLIMIT,AMSLL,AMLGE,DSLL,DLGE)                  MAIN
      WWMASS(2)=AMLGE                                                   MAIN
      WMASS(2)=AMSLL                                                    MAIN
      IF(WMASS(2).LT.0.0) WMASS(2)=0.0                                  MAIN
      IF(WWMASS(2).LT.0.0) WWMASS(2)=0.0                                MAIN
      WTMASS(2)=WWMASS(2)+WMASS(2)                                      MAIN
      VMASS(2)=VMASS(1)                                                 MAIN
      MMASS=AMASS+CHMASS+VMASS(2)+WTMASS(2)                             MAIN
      TMASS(2)=MMASS                                                    MAIN
      GMASS(2)=TMASS(2)-WTMASS(2)                                       MAIN
      DAVE(N)=DSLL                                                      MAIN
      DDAVE(N)=DLGE                                                     MAIN
      XW(2)=WMASS(2)/MMASS                                              MAIN
      XWW(2)=WWMASS(2)/MMASS                                            MAIN
      XWT(2)=WTMASS(2)/MMASS                                            MAIN
      XV(2)=XV(1)                                                       MAIN
      XCH4=CHMASS/MMASS                                                 MAIN
      XA=AMASS/MMASS                                                    MAIN
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      XG=XA+XV(2)+XCH4                                                  MAIN
      XAIR(2)=XA                                                        MAIN
      XMETAN(2)=XCH4                                                    MAIN
      XGAS(2)=XG                                                        MAIN
      WS(2)=VMASS(2)/AMASS                                              MAIN
      PW=WS(2)*P(2)/(WS(2)+0.6219)                                      MAIN
      TDEW(2)=WICBPT(TG(2),PW)                                          MAIN
      RHOA(2)=P(2)/RA/TG(2)                                             MAIN
      CALL WICPRP(XA,XV(2),XCH4,TG(2),RMIX,CPMIX,GAMMA,G1,G2,G3)        MAIN
      RHOG(2)=P(2)/RMIX/TG(2)                                           MAIN
      IF(JPERFM.NE.3) BMASS=MMASS                                       MAIN
      IF(JPERFM.EQ.3) BMASS=GMASS(2)                                    MAIN
      CALL WICMAC(ISTAGE,BMASS,TG(2),P(2),M,VZ,C,XWT(2),ALFA2,          MAIN
     $RMIX,CPMIX,AAA2)                                                  MAIN
      RHOG(2)=(1.0+G2*M**2)**G3*RHOG(2)                                 MAIN
      RHOM(2)=1.0/((1.0-XWT(2))/RHOG(2)+XWT(2)/RHOW)                    MAIN
      RHOA(2)=(1.0+G2*M**2)**G3*RHOA(2)                                 MAIN
      IF(IPRINT.EQ.2) WRITE(6,614) VZ,ALFA,D1,D2,D3,WWMASS(2),          MAIN
     $WMASS(2),VMASS(2),XW(2),XV(2)                                     MAIN
  614 FORMAT(1H ,10(F12.5,1X))                                          MAIN
      IF(IPRINT.EQ.2) WRITE(6,615)WS(2),DAVE(N),DDAVE(N),RHOM(2),RHOA   MAIN
     $(2),RHOM(2),RHOG(2)                                               MAIN
  615 FORMAT(1H ,7(F12.5,1X))                                           MAIN
      IF(VZ.LT.0.0.OR.VZ.GT.1500.0) WRITE(6,6150)                       MAIN
 6150 FORMAT(1H0,≠VZ IS TOO HIGH OR TOO LOW: VZ=≠,F10.4)                MAIN
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ MAIN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC MAIN
C                                                                     C MAIN
C CENYRIFUGAL ACTION IN ROTOR                                         C MAIN
C                                                                     C MAIN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC MAIN
C CENTRIFUGAL EFFECT IN ROTOR(SMALL DROPLET)                            MAIN
      IF(IPRINT.EQ.2) WRITE(6,8040)                                     MAIN
 8040 FORMAT(1H0,≠CENTRIFUGAL ACTION IN ROTOR (SMALL DROPLET)≠)         MAIN
      DELMW=0.0                                                         MAIN
      DELMAS=0.0                                                        MAIN
      RW=0.0                                                            MAIN
      RWW=0.0                                                           MAIN
      IF(WTMASS(1).GT.1.0E-6) RW=WMASS(1)/WTMASS(1)                     MAIN
      IF(WTMASS(1).GT.1.0E-6) RWW=WWMASS(1)/WTMASS(1)                   MAIN
      AMASW=(WMASTL-WCENT-WWCENT)*RW                                    MAIN
      BMASW=(WMASTL-WCENT-WWCENT)*RWW*XWWB                              MAIN
      IF(DAVE(N-1).LT.1.0E-6) GO TO 996                                 MAIN
      DD=DAVE(N-1)                                                      MAIN
      DELZZ=RC(ISTAGE)/12.0                                             MAIN
      ALFAAV=(BETA1+BETA2)/2.0                                          MAIN
      IRS=2                                                             MAIN
      RHOGAS=RHOG(2)                                                    MAIN
      RHUB=RRHUB(ISTAGE)                                                MAIN
      CALL WICCEN(RZERO,UZERO,DD,VZ,DELZZ,ALFAAV ,FN,IRS,RHOGAS,        MAIN
     1RHUB,R2,U2,ITIP,VZTIME,XG,XA,XV(2),XCH4,RRTIP(ISTAGE))            MAIN
      CALL WICDMS(IPRINT,IRAD,WMASS(1),AMASW,AMASW,RZERO,R2,AAREA(ISTA  MAIN
     $GE),RADI1(ISTAGE),RRTIP(ISTAGE),DMIN,DMOUT,AMASW2,DELMAS)         MAIN
      WCENT=DELMAS                                                      MAIN
      RZERO=R2                                                          MAIN
      UZERO=U2                                                          MAIN
  996 DELMW=DELMAS                                                      MAIN
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ MAIN
C CENTRIFUGAL EFFECT IN ROTOR(LARGE DROPLET)                            MAIN
      IF(IPRINT.EQ.2) WRITE(6,8050)                                     MAIN
 8050 FORMAT(1H0,≠ CENTRIFUGAL ACTION IN ROTOR (LARGE DROPLET)≠)        MAIN
      DELMAS=0.0                                                        MAIN
      DELMWW=0.0                                                        MAIN
      IF(DDAVE(N-1).LT.1.0E-6) GO TO 9996                               MAIN
      DD=DDAVE(N-1)                                                     MAIN
      DELZZ=RC(ISTAGE)/12.0                                             MAIN
      ALFAAV=0.0                                                        MAIN
      IIRS=2                                                            MAIN
      RHOGAS=RHOG(2)                                                    MAIN
      RHUB=RRHUB(ISTAGE)                                                MAIN
```

```
      CALL WICCEN(RRZERO,UUZERO,DD,VZ,DELZZ,ALFAAV ,FN,IIRS,RHOGAS,
     1RHUB,R2,U2,IITIP,VZTIME,XG,XA,XV(2),XCH4,RRTIP(ISTAGE))
      CALL WICDML(IPRINT,IRAD,WWMASS(1),BMASW,BMASW,RRZERO,R2,AAREA(IS
     $TAGE),RADI1(ISTAGE),RRTIP(ISTAGE),DMIN,DMOUT,AMASW2,DELMAS)
      RRZERO=R2
      UUZERO=U2
 9996 DELMWW=DELMAS
      WM=WMASS(2)
      WWM=WWMASS(2)
      WMASS(2)=WMASS(2)+DELMW
      WWMASS(2)=WWMASS(2)+DELMWW
      WTMASS(2)=WMASS(2)+WWMASS(2)
      IF(WTMASS(2).GT.WMASTL) TT=WTMASS(2)/WMASTL
      IF(WTMASS(2).GT.WMASTL) WMASS(2)=WMASS(2)/TT
      IF(WTMASS(2).GT.WMASTL) WWMASS(2)=WWMASS(2)/TT
      DELMW=WMASS(2)-WM
      DELMWW=WWMASS(2)-WWM
      WTMASS(2)=WMASS(2)+WWMASS(2)
      DELMAS=WTMASS(2)-WTMASS(1)
      MMASS=MMASS+DELMAS
      XW(2)=WMASS(2)/MMASS
      XWW(2)=WWMASS(2)/MMASS
      XV(2)=VMASS(2)/MMASS
      XA=AMASS/MMASS
      XCH4=CHMASS/MMASS
      XG=XA+XV(2)+XCH4
      DELVUM=RHOG(2)/RHOW*DELMAS
      AMASS=AMASS-DELVUM*(AMASS/GMASS(2))
      VMASS(2)=VMASS(2)-DELVUM*(VMASS(2)/GMASS(2))
      CHMASS=CHMASS-DELVUM*(CHMASS/GMASS(2))
      MMASS=AMASS+VMASS(2)+CHMASS+WTMASS(2)
      WS(2)=VMASS(2)/MMASS
      WCENT=WCENT+DELMW
      WWCENT=WWCENT+DELMWW
      IF(WMASS(2).LT.1.0E-6) DAVE(N)=0.0
      IF(WWMASS(2).LT.1.0E-6) DDAVE(N)=0.0
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                     C
C STATOR IMPINGEMENT                                                  C
C                                                                     C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C STATOR IMPINGEMENT(SMALL DROPLET)
      IF(IPRINT.EQ.2) WRITE(6,8060)
 8060 FORMAT(1H0,≠ STATOR IMPINGEMENT (SMALL DROPLET)≠)
      CALL WICISS(ISTAGE,RADI2(ISTAGE),XW(2),XG,RHOG(2),ALFA2,V2,
     $WW1,WW2,WW)
      AMIMPS=WW
      IF(AMIMPS.GT.WMASS(2)) AMIMPS=WMASS(2)
      IF(AMIMPS.LT.0.0) AMIMPS=0.0
      AMREBS=AMIMPS*PREB/100.0
      AMWAKS=AMIMPS*(1.0-PREB/100.0)
      IF(IPRINT.EQ.2) WRITE(6,617) XW(2),XG,RHOG(2),V2,WW,AMIMPS,AMRE
     $BS,AMWAKS
  617 FORMAT(1H ,8(F12.5,1X))
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C STATOR IMPINGEMENT(LARGE DROPLET)
      IF(IPRINT.EQ.2) WRITE(6,8070)
 8070 FORMAT(1H0,≠ STATOR IMPINGEMENT (LARGE DROPLET)≠)
      CALL WICISL(ISTAGE,RADI2(ISTAGE),XWW(2),XG,RHOG(2),ALFA2,V2,WW1
     $,WW2,WW)
      BMIMPS=WW
      IF(BMIMPS.LT.0.0) BMIMPS=0.0
      IF(BMIMPS.GT.WWMASS(2)) BMIMPS=WWMASS(2)
      BMREBS=BMIMPS*PREB/100.0
      BMWAKS=BMIMPS*(1.0-PREB/100.0)
      IF(IPRINT.EQ.2) WRITE(6,6617) XWW(2),XA,RHOA(2),VZ,WW,BMIMPS,BM
     $REBS,BMWAKS
 6617 FORMAT(1H ,8(F12.5,1X))
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
```

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  MAIN
C                                                                     C  MAIN
C STATOR WAKE                                                         C  MAIN
C                                                                     C  MAIN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  MAIN
      IF(IPRINT.EQ.2) WRITE(6,8080)                                      MAIN
 8080 FORMAT(1H0,≠ STATOR WAKE≠)                                         MAIN
      N=N+1                                                              MAIN
      ALFA=ALFA3                                                         MAIN
      DWAKEM=0.0                                                         MAIN
      IF(AMWAKS.GT.0.0) GO TO 632                                        MAIN
      GO TO 633                                                          MAIN
  632 CALL WICWAK(RHOG(2),V3,DWAKE,DWAKEM)                               MAIN
  633 D1=DWAKEM                                                          MAIN
      IF(D1.LT.0.0) D1=0.0                                               MAIN
      IF(D1.GT.DIN) D1=DIN                                               MAIN
      AMING1=AMWAKS                                                      MAIN
      ALFA=ALFA3                                                         MAIN
      SDELV1=DELVU2                                                      MAIN
      DWAKEM=0.0                                                         MAIN
      IF(BMWAKS.GT.0.0) GO TO 6330                                       MAIN
      GO TO 6331                                                         MAIN
 6330 CALL WICWAK(RHOG(2),SDELV1,DWAKE,DWAKEM)                           MAIN
 6331 D2=DWAKEM                                                          MAIN
      IF(D2.LT.0.0) D2=0.0                                               MAIN
      IF(D2.GT.DDIN) D2=DDIN                                             MAIN
      SUP2=(90.0-ALFA3)/180.0                                            MAIN
      AMING2=BMWAKS*SUP2                                                 MAIN
      SDELV2=DELVL2                                                      MAIN
      DWAKEM=0.0                                                         MAIN
      IF(BMWAKS.GT.0.0) GO TO 6332                                       MAIN
      GO TO 6333                                                         MAIN
 6332 CALL WICWAK(RHOG(2),SDELV2,DWAKE,DWAKEM)                           MAIN
 6333 D3=DWAKEM                                                          MAIN
      IF(D3.LT.0.0) D3=0.0                                               MAIN
      IF(D3.GT.DDIN) D3=DDIN                                             MAIN
      SLOW2=(90.0+ALFA3)/180.0                                           MAIN
      AMING3=BMWAKS*SLOW2                                                MAIN
      WMASSS=WMASS(2)-AMWAKS                                             MAIN
      WMASSL=WWMASS(2)-BMWAKS                                            MAIN
      IF(WMASSS.LT.0.0) WMASSS=0.0                                       MAIN
      IF(WMASSL.LT.0.0) WMASSL=0.0                                       MAIN
      CALL WICSIZ(WMASSL,WMASSS,AMING1,AMING2,AMING3,DDAVE(2),DAVE(      MAIN
     $2),D1,D2,D3,DLIMIT,AMSLL,AMLGE,DSLL,DLGE)                          MAIN
      WWMASS(3)=AMLGE                                                    MAIN
      WMASS(3)=AMSLL                                                     MAIN
      IF(WMASS(3).LT.0.0) WMASS(3)=0.0                                   MAIN
      IF(WWMASS(3).LT.0.0) WWMASS(3)=0.0                                 MAIN
      WTMASS(3)=WWMASS(2)+WMASS(2)                                       MAIN
      VMASS(3)=VMASS(2)                                                  MAIN
      MMASS=AMASS+CHMASS+VMASS(3)+WTMASS(3)                              MAIN
      TMASS(3)=MMASS                                                     MAIN
      GMASS(3)=TMASS(3)-WTMASS(3)                                        MAIN
      DAVE(N)=DSLL                                                       MAIN
      DDAVE(N)=DLGE                                                      MAIN
      XW(3)=WMASS(3)/MMASS                                               MAIN
      XWW(3)=WWMASS(3)/MMASS                                             MAIN
      XWT(3)=WTMASS(3)/MMASS                                             MAIN
      XV(3)=XV(2)                                                        MAIN
      XA=AMASS/MMASS                                                     MAIN
      XCH4=CHMASS/MMASS                                                  MAIN
      XG=XA+XV(3)+XCH4                                                   MAIN
      XAIR(3)=XA                                                         MAIN
      XMETAN(3)=XCH4                                                     MAIN
      XGAS(3)=XG                                                         MAIN
      IF(WMASSO.LT.1.0E-6) WMASSO=WMASS(3)                               MAIN
      IF(WWMASO.LT.1.0E-6) WWMASO=WWMASS(3)                              MAIN
      IF(WTMASS(3).GT.0.0) RW=WMASS(3)/WTMASS(3)                         MAIN
      IF(WTMASS(3).GT.0.0) RWW=WWMASS(3)/WTMASS(3)                       MAIN
      TG(3)=TG(2)                                                        MAIN
```

```
      TW(3)=TW(2)
      IF(IPRINT.EQ.2) WRITE(6,619) RHOA(2),VZ,ALFA,D1,D2,WWMASS(3)
     $,WMASS(3),VMASS(3),XW(3),XV(3)
  619 FORMAT(1H ,10(F12.5,1X))
      IF(IPRINT.EQ.2) WRITE(6,620) DAVE(N),TG(3),TW(3)
  620 FORMAT(1H ,3(F12.5,1X))
      IF(WMASS(2).GT.0.0.AND.WWMASS(2).GT.0.0) GO TO 951
      IF(WMASS(2).GT.0.0) GO TO 951
      IF(WWMASS(2).GT.0.0) GO TO 951
      WS(3)=WS(2)
      TB(3)=TB(2)
      TDEW(3)=TDEW(2)
      DELTG2=0.0
      DELTG3=0.0
      DELTW2=0.0
      TRATIO=TG(3)/TG(1)
      DAVE(N)=0.0
      RHOA(3)=P(3)/RA/TG(3)
      CALL WICPRP(XA,XV(3),XCH4,TG(3),RMIX,CPMIX,GAMMA,G1,G2,G3)
      RHOG(3)=P(3)/RMIX/TG(3)
      IF(JPERFM.NE.3) BMASS=MMASS
      IF(JPERFM.EQ.3) BMASS=GMASS(3)
      CALL WICMAC(ISTAGE,BMASS,TG(3),P(3),M,VZ,C,XWT(3),ALFA3,
     $RMIX,CPMIX,AAA3)
      RHOG(3)=(1.0+G2*M**2)**G3*RHOG(3)
      RHOM(3)=1.0/((1.0-XWT(3))/RHOG(3)+XWT(3)/RHOW)
      RHOA(3)=(1.0+G2*M**2)**G3*RHOA(3)
      GO TO 950
  951 CONTINUE
      WTMASS(3)=WMASS(3)+WWMASS(3)
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                       C
C HEAT TRANSFER CALCULATION                                             C
C                                                                       C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C HEAT-TRANSFER (SMALL DROPLET)
      IF(IPRINT.EQ.2) WRITE(6,8120)
 8120 FORMAT(1H0,≠ HEAT TRANSFER≠)
      DELTGH=0.0
      DELTWH=0.0
      IF(DAVE(N-2).GT.0.0.AND.DAVE(N).GT.0.0) GO TO 8121
      GO TO 8122
 8121 RE=0.0
      XV1=(XV(1)+XV(3))/2.0
      XW1=(XW(1)+XW(3))/2.0
      WMASS1=(WMASS(1)+WMASS(3))/2.0
      VMASS1=(VMASS(1)+VMASS(3))/2.0
      CPG1=XA*WICCPA(TG(1))+XV(1)*WICCPH(TG(1))+XCH4*WICCPC(TG(1))
      CPG3=XA*WICCPA(TG(3))+XV(3)*WICCPH(TG(3))+XCH4*WICCPC(TG(3))
      CPG=(CPG1+CPG3)/2.0
      CALL WICHET(TG(1),TG(3),TW(1),TW(3),DAVE(N-2),DAVE(N)
     $,DELZ(ISTAGE),VZ,WMASS1,VMASS1,AMASS,CHMASS,CPG,CPW,DELTGH
     $,DELTWH,RE)
 8122 DELTG2=DELTGH
      DELTW2=DELTWH
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C HEAT TRANSFER(LARGE DROPLET)
      DELTGH=0.0
      DELTWH=0.0
      IF(DDAVE(N-2).GT.0.0.AND.DAVE(N).GT.0.0) GO TO 8123
      GO TO 8124
 8123 RE=0.0
      IF(DDAVE(N-1).GT.0.0) RE=REAVE
      XV1=(XV(1)+XV(3))/2.0
      XW1=(XWW(1)+XWW(3))/2.0
      WMASS1=(WWMASS(1)+WWMASS(3))/2.0
      VMASS1=(VMASS(1)+VMASS(3))/2.0
      CPG1=XA*WICCPA(TG(1))+XV(1)*WICCPH(TG(1))+XCH4*WICCPC(TG(1))
      CPG3=XA*WICCPA(TG(1))+XV(3)*WICCPH(TG(3))+XCH4*WICCPC(TG(3))
```

```
      CPG=(CPG1+CPG3)/2.0
      CALL WICHET(TG(1),TG(3),TWW(1),TWW(3),DDAVE(N-2),DDAVE(N)
     $,DELZ(ISTAGE),VZ,WMASS1,VMASS1,AMASS,CHMASS,CPG,CPW,DELTGH
     $,DELTWH,RE)
 8124 DELTG3=DELTGH
      DELTW3=DELTWH
      TG(3)=TG(1)+DELTG1-DELTG2-DELTG3
      TW(3)=TW(1)+DELTW1+DELTW2
      TWW(3)=TWW(1)+DELTW3
      TRATIO=TG(3)/TG(1)
      IF(IPRINT.EQ.2) WRITE(6,627) DELTG2,DELTW2,DELTG3,DELTW3,TG(3),
     $TW(3),TWW(3),TRATIO
  627 FORMAT(1H ,8(F15.6,1X))
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C MASS TRANSFER CALCULATION                                            C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      IF(IPRINT.EQ.2) WRITE(6,8130)
 8130 FORMAT(1H0,≠ MASS TRANSFER≠)
      DAVEN2=DAVE(N-2)
      DAVEN=DAVE(N)
      DZ=DELZ(ISTAGE)
      RE=0.0
      DMDTAV=0.0
      IF(DAVE(N-2).GT.0.0.AND.DAVE(N).GT.0.0) GO TO 636
      GO TO 637
  636 CALL WICMAS(WS(1),TW(1),TW(3),P(1),P(3),TG(1),TG(3),DZ,PWB1,PWB2
     $,PW1,PW2,VZ,DAVEN2,DAVEN,HW2,VMASS(1),VMASS2,WMASS(1),WMASS2,
     $DMDTAV,AMASS,RE)
  637 DMDTA1=DMDTAV
      IF(DMDTA1.LT.0.0) DMDTA1=0.0
      DAVEN2=DDAVE(N-2)
      DAVEN=DDAVE(N)
      DZ=DELZ(ISTAGE)
      RE=0.0
      DMDTAV=0.0
      IF(DDAVE(N-1).GT.0.0.AND.DDAVE(N).GT.0.0) RE=REAVE
      IF(DDAVE(N-2).GT.0.0.AND.DDAVE(N).GT.0.0) GO TO 6360
      GO TO 6370
 6360 CALL WICMAS(WS(1),TWW(1),TWW(3),P(1),P(3),TG(1),TG(3),DZ,PWB1,PWB2
     $,PW1,PW2,VZ,DAVEN2,DAVEN,HW2,VMASS(1),VMASS2,WWMASS(1),WMASS2,
     $DMDTAV,AMASS,RE)
 6370 DMDTA2=DMDTAV
      IF(DMDTA2.LT.0.0) DMDTA2=0.0
      WMASS(3)=WMASS(3)-DMDTA1
      WWMASS(3)=WWMASS(3)-DMDTA2
      WMASTL=WMASTL-(DMDTA1+DMDTA2)*AAREAS(ISTAGE)/AAA2
      IF(WMASTL.LT.0.0) WMASTL=0.0
      IF(WMASS(3).LT.0.0) WMASS(3)=0.0
      IF(WWMASS(3).LT.0.0) WWMASS(3)=0.0
      WTMASS(3)=WMASS(3)+WWMASS(3)
      VMASS(3)=VMASS(3)+DMDTA1+DMDTA2
      MMASS=AMASS+CHMASS+VMASS(3)+WTMASS(3)
      TMASS(3)=MMASS
      GMASS(3)=TMASS(3)-WTMASS(3)
      XW(3)=WMASS(3)/MMASS
      XWW(3)=WWMASS(3)/MMASS
      XWT(3)=WTMASS(3)/MMASS
      XV(3)=VMASS(3)/MMASS
      XA=AMASS/MMASS
      XCH4=CHMASS/MMASS
      XG=XA+XV(3)+XCH4
      XAIR(3)=XA
      XMETAN(3)=XCH4
      XGAS(3)=XG
      WS(3)=VMASS(3)/AMASS
      PW=WS(3)*P(3)/(WS(3)+0.6219)
      TDEW(3)=WICBPT(TG(3),PW)
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      RHOA(3)=P(3)/RA/TG(3)
      CALL WICPRP(XA,XV(3),XCH4,TG(3),RMIX,CPMIX,GAMMA,G1,G2,G3)
      RHOG(3)=P(3)/RMIX/TG(3)
      IF(JPERFM.NE.3) BMASS=MMASS
      IF(JPERFM.EQ.3) BMASS=GMASS(3)
      CALL WICMAC(ISTAGE,BMASS,TG(3),P(3),M,VZ,C,XWT(3),ALFA3,
     $RMIX,CPMIX,AAA3)
      RHOG(3)=(1.0+G2*M**2)**G3*RHOG(3)
      RHOM(3)=1.0/((1.0-XWT(3))/RHOG(3)+XWT(3)/RHOW)
      RHOA(3)=(1.0+G2*M**2)**G3*RHOG(3)
      TB(3)=WICBPT(TG(3),P(3))
      IF(IPRINT.EQ.2) WRITE(6,624) WWMASS(3),XWW(3),DDAVE(N),WMASS(3),
     $VMASS(3),XW(3),XV(3),WS(3),DAVE(N)
  624 FORMAT(1H ,9(F12.5,1X))
      IF(IPRINT.EQ.2) WRITE(6,625) RHOA(3),RHOM(3),RHOG(3),DMDTA1,DMD
     $TA2,PW2,TW(3),TG(3)
  625 FORMAT(1H ,8(F12.5,1X))
  950 DELTGW=DELTG1
      DELTDW=DELTW1
      DELTGH=-DELTG2-DELTG3
      DELTDH=DELTW2
      DELP=P(3)-P(1)
      GAMMAO=GAMMA
      TB(3)=WICBPT(TG(3),P(3))
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                    C
C OUTPUT(STAGE PERFORMANCE)                                          C
C                                                                    C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      IF(IUNIT.NE.2) GO TO 853
      WMASS(1)=WMASS(1)*CFM
      WMASS(3)=WMASS(3)*CFM
      WWMASS(1)=WWMASS(1)*CFM
      WWMASS(3)=WWMASS(3)*CFM
      WTMASS(1)=WTMASS(1)*CFM
      WTMASS(3)=WTMASS(3)*CFM
      AMASS=AMASS*CFM
      CHMASS=CHMASS*CFM
      VMASS(1)=VMASS(1)*CFM
      VMASS(3)=VMASS(3)*CFM
      GMASS(1)=GMASS(1)*CFM
      GMASS(3)=GMASS(3)*CFM
      TMASS(1)=TMASS(1)*CFM
      TMASS(3)=TMASS(3)*CFM
      RHOA(1)=RHOA(1)*CFD
      RHOA(2)=RHOA(2)*CFD
      RHOA(3)=RHOA(3)*CFD
      RHOM(1)=RHOM(1)*CFD
      RHOM(2)=RHOM(2)*CFD
      RHOM(3)=RHOM(3)*CFD
      RHOG(1)=RHOG(1)*CFD
      RHOG(2)=RHOG(2)*CFD
      RHOG(3)=RHOG(3)*CFD
      TG(1)=TG(1)*CFT
      TG(2)=TG(2)*CFT
      TG(3)=TG(3)*CFT
      TW(1)=TW(1)*CFT
      TW(2)=TW(2)*CFT
      TW(3)=TW(3)*CFT
      TWW(1)=TWW(1)*CFT
      TWW(2)=TWW(2)*CFT
      TWW(3)=TWW(3)*CFT
      P(1)=P(1)*CFP
      P(2)=P(2)*CFP
      P(3)=P(3)*CFP
      TB(1)=TB(1)*CFT
      TB(2)=TB(2)*CFT
      TB(3)=TB(3)*CFT
      TDEW(1)=TDEW(1)*CFT
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      TDEW(2)=TDEW(2)*CFT                                                MAIN
      TDEW(3)=TDEW(3)*CFT                                                MAIN
  853 CONTINUE                                                           MAIN
      WRITE(6,400) FAIO,ISTAGE                                           MAIN
  400 FORMAT(1H1,1X,≠*********************  ≠,1X,                         MAIN
     $≠INITIAL FLOW COEFFICIENT=≠,1X,F7.5,1X,≠(ISTAGE= ≠,I2,1X,          MAIN
     $≠)≠,2X,≠**********************≠)                                   MAIN
      PRATIO=P(3)/P(1)                                                   MAIN
      TRATIO=TG(3)/TG(1)                                                 MAIN
      GAMMAV=(GAMMAS+GAMMAO)/2.0                                         MAIN
      G4=(GAMMAV-1.0)/GAMMAV                                             MAIN
      ETAA(ISTAGE)=(PRATIO**G4-1.0)/(TRATIO-1.0)                         MAIN
      WRITE(6,402) JPERFM                                                MAIN
  402 FORMAT(1H0,5X,≠STAGE PERFORMANCE AFTER INTER-STAGE ADJUSTMENT≠,    MAIN
     $≠(JPERFM=≠,I1,≠)≠)                                                 MAIN
      WRITE(6,401) PRATIO,TRATIO,ETAA(ISTAGE)                            MAIN
  401 FORMAT(1H0,5X,≠STAGE TOTAL PRESSURE RATIO=≠,F12.5,/,               MAIN
     $6X,≠STAGE TOTAL TEMPERATURE RATIO=≠,F12.5,/,                       MAIN
     $6X,≠STAGE ADIABATIC EFFICIENCY=≠,F12.5)                            MAIN
      WRITE(6,4025)                                                      MAIN
 4025 FORMAT(1H0,12X,≠**STAGE INLET**≠,4X,≠**STAGE OUTLET**≠,            MAIN
     $4X,≠**STAGE OUTLET**≠)                                             MAIN
      WRITE(6,4026)                                                      MAIN
 4026 FORMAT(1H ,33X,≠(BEFORE INTER-≠,6X,≠(AFTER INTER-≠)                MAIN
      WRITE(6,4027)                                                      MAIN
 4027 FORMAT(1H ,34X,≠STAGE ADJUST-≠,7X,≠STAGE ADJUST-≠)                 MAIN
      WRITE(6,4028)                                                      MAIN
 4028 FORMAT(1H ,34X,≠MENT)≠,15X,≠MENT)≠)                                MAIN
      WRITE(6,405) XV(1), XV(1), XV(3)                                   MAIN
  405 FORMAT(1H ,5X,≠XV=≠,3(F15.5,5X))                                   MAIN
      WRITE(6,406) XW(1), XW(1) , XW(3)                                  MAIN
  406 FORMAT(1H ,5X,≠XW=≠,3(F15.5,5X))                                   MAIN
      WRITE(6,4060) XWW(1),XWW(1),XWW(3)                                 MAIN
 4060 FORMAT(1H ,5X,≠XWW=≠,3(F15.5,5X))                                  MAIN
      WRITE(6,4061) XWT(1),XWT(1),XWT(3)                                 MAIN
 4061 FORMAT(1H ,5X,≠XWT=≠,3(F15.5,5X))                                  MAIN
      WRITE(6,4062) XAIR(1),XAIR(1),XAIR(3)                              MAIN
 4062 FORMAT(1H ,5X,≠XAIR=≠,3(F15.5,5X))                                 MAIN
      WRITE(6,4063) XMETAN(1),XMETAN(1),XMETAN(3)                        MAIN
 4063 FORMAT(1H ,5X,≠XMETAN=≠,3(F15.5,5X))                               MAIN
      WRITE(6,4064) XGAS(1),XGAS(1),XGAS(3)                              MAIN
 4064 FORMAT(1H ,5X,≠XGAS≠,3(F15.5,5X))                                  MAIN
      WRITE(6,407) WMASS(1), WMASS(1) , WMASS(3)                         MAIN
  407 FORMAT(1H ,5X,≠WMASS=≠,3(F15.5,5X))                                MAIN
      WRITE(6,4070) WWMASS(1),WWMASS(1),WWMASS(3)                        MAIN
 4070 FORMAT(1H ,5X,≠WWMASS=≠,3(F15.5,5X))                               MAIN
      WRITE(6,4071) WTMASS(1),WTMASS(1),WTMASS(3)                        MAIN
 4071 FORMAT(1H ,5X,≠WTMASS=≠,3(F15.5,5X))                               MAIN
      WRITE(6,4072) AMASS,AMASS,AMASS                                    MAIN
 4072 FORMAT(1H ,5X,≠AMASS=≠,3(F15.5,5X))                                MAIN
      WRITE(6,4073) CHMASS,CHMASS,CHMASS                                 MAIN
 4073 FORMAT(1H ,5X,≠CHMASS=≠,3(F15.5,5X))                               MAIN
      WRITE(6,408) VMASS(1) , VMASS(1) , VMASS(3)                        MAIN
  408 FORMAT(1H ,5X,≠VMASS=≠,3(F15.5,5X))                                MAIN
      WRITE(6,4080) GMASS(1),GMASS(1),GMASS(3)                           MAIN
 4080 FORMAT(1H ,5X,≠GMASS=≠,3(F15.5,5X))                                MAIN
      WRITE(6,4081) TMASS(1),TMASS(1),TMASS(3)                           MAIN
 4081 FORMAT(1H ,5X,≠TMASS=≠,3(F15.5,5X))                                MAIN
      WRITE(6,409) WS(1) , WS(1) , WS(3)                                 MAIN
  409 FORMAT(1H ,5X,≠WS=≠,3(F15.5,5X))                                   MAIN
      WRITE(6,410) RHOA(1) , RHOA(2) , RHOA(3)                           MAIN
  410 FORMAT(1H ,5X,≠RHOA=≠,3(F15.5,5X))                                 MAIN
      WRITE(6,411) RHOM(1), RHOM(2),RHOM(3)                              MAIN
  411 FORMAT(1H ,5X,≠RHOM=≠,3(F15.5,5X))                                 MAIN
      WRITE(6,412) RHOG(1),RHOG(2),RHOG(3)                               MAIN
  412 FORMAT(1H ,5X,≠RHOG=≠,3(F15.5,5X))                                 MAIN
      WRITE(6,413) TG(1),TG(2),TG(3)                                     MAIN
  413 FORMAT(1H ,5X,≠TG=≠,3(F15.5,5X))                                   MAIN
      WRITE(6,414) TW(1),TW(2),TW(3)                                     MAIN
  414 FORMAT(1H ,5X,≠TW=≠,3(F15.5,5X))                                   MAIN
```

```
      WRITE(6,4140) TWW(1),TWW(2),TWW(3)
 4140 FORMAT(1H ,5X,≠TWW=≠,3(F15.5,5X))
      WRITE(6,415) P(1),P(2),P(3)
  415 FORMAT(1H ,5X,≠P=≠,3(F15.5,5X))
      WRITE(6,416) TB(1),TB(2),TB(3)
  416 FORMAT(1H ,5X,≠TB=≠,3(F15.5,5X))
      WRITE(6,422) TDEW(1),TDEW(2),TDEW(3)
  422 FORMAT(1H ,5X,≠TDEW=≠,3(F15.5,5X))
      IF(IUNIT.NE.2) GO TO 854
      WMASS(1)=WMASS(1)/CFM
      WMASS(3)=WMASS(3)/CFM
      WWMASS(1)=WWMASS(1)/CFM
      WWMASS(3)=WWMASS(3)/CFM
      WTMASS(1)=WTMASS(1)/CFM
      WTMASS(3)=WTMASS(3)/CFM
      AMASS=AMASS/CFM
      CHMASS=CHMASS/CFM
      VMASS(1)=VMASS(1)/CFM
      VMASS(3)=VMASS(3)/CFM
      GMASS(1)=GMASS(1)/CFM
      GMASS(3)=GMASS(3)/CFM
      TMASS(1)=TMASS(1)/CFM
      TMASS(3)=TMASS(3)/CFM
      RHOA(1)=RHOA(1)/CFD
      RHOA(2)=RHOA(2)/CFD
      RHOA(3)=RHOA(3)/CFD
      RHOM(1)=RHOM(1)/CFD
      RHOM(2)=RHOM(2)/CFD
      RHOM(3)=RHOM(3)/CFD
      RHOG(1)=RHOG(1)/CFD
      RHOG(2)=RHOG(2)/CFD
      RHOG(3)=RHOG(3)/CFD
      TG(2)=TG(2)/CFT
      TG(3)=TG(3)/CFT
      TW(1)=TW(1)/CFT
      TW(2)=TW(2)/CFT
      TW(3)=TW(3)/CFT
      TWW(1)=TWW(1)/CFT
      TWW(2)=TWW(2)/CFT
      TWW(3)=TWW(3)/CFT
      P(1)=P(1)/CFP
      P(2)=P(2)/CFP
      P(3)=P(3)/CFP
      TB(1)=TB(1)/CFT
      TB(2)=TB(2)/CFT
      TB(3)=TB(3)/CFT
      TDEW(1)=TDEW(1)/CFT
      TDEW(2)=TDEW(2)/CFT
      TDEW(3)=TDEW(3)/CFT
  854 CONTINUE
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                       C
C BOILING                                                               C
C                                                                       C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      IF(XDIN.GT.0.0) GO TO 460
      GO TO 450
  460 IF(TW(3).LT.TB(3)) GO TO 450
      HV=1115.3272-0.6840905*(TB(3)-460.0)
      DAMY=CPG/HV*(TG(3)-TB(3))
      XE=DAMY/(DAMY+1.0)
      IF(XE.GT.XW(3)) GO TO 451
      XEVAPO=XE
      TW(3)=TB(3)
      TG(3)=TB(3)
      XW(3)=XW(3)-XEVAPO
      XV(3)=XV(3)+XEVAPO
      GO TO 452
  451 XEVAPO=XW(3)
```

```
      TW(3)=0.0                                                          MAIN
      TG(3)=TG(3)-XW(3)/(1.0-XW(3))*HV/CPG                               MAIN
      XW(3)=0.0                                                          MAIN
      XV(3)=XV(3)+XEVAPO                                                 MAIN
  452 WMASS(3)=XW(3)*MMASS                                               MAIN
      VMASS(3)=XV(3)*MMASS                                               MAIN
      GMASS(3)=VMASS(3)+AMASS                                            MAIN
      IF(IPRINT.EQ.2) WRITE(6,453)                                       MAIN
  453 FORMAT(1H0,≠BOILING≠)                                              MAIN
      IF(IPRINT.EQ.2) WRITE(6,454) HV,XEVAPO,TW(3),TG(3),XW(3),XV(3)     MAIN
     $,WMASS(3),GMASS,VMASS(3),MMASS                                     MAIN
  454 FORMAT(1H0,10(F10.5,2X))                                           MAIN
  450 CONTINUE                                                           MAIN
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ MAIN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC MAIN
C                                                                      C MAIN
C BLEED                                                                C MAIN
C                                                                      C MAIN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC MAIN
      AMASS=AMASS*(1.0+XG1BLD(ISTAGE))                                   MAIN
      CHMASS=CHMASS*(1.0+XG3BLD(ISTAGE))                                 MAIN
      VMASS(3)=VMASS(3)*(1.0+XG2BLD(ISTAGE))                             MAIN
      WMASS(3)=WMASS(3)*(1.0+XWBLD(ISTAGE))                              MAIN
      WWMASS(3)=WWMASS(3)*(1.0+XWWBLD(ISTAGE))                           MAIN
      WTMASS(3)=WMASS(3)+WWMASS(3)                                       MAIN
      MMASS=AMASS+CHMASS+VMASS(3)+WTMASS(3)                              MAIN
      TMASS(3)=MMASS                                                     MAIN
      GMASS(3)=TMASS(3)-WTMASS(3)                                        MAIN
      XW(3)=WMASS(3)/MMASS                                               MAIN
      XWW(3)=WWMASS(3)/MMASS                                             MAIN
      XWT(3)=WTMASS(3)/MMASS                                             MAIN
      XV(3)=VMASS(3)/MMASS                                               MAIN
      XA=AMASS/MMASS                                                     MAIN
      XCH4=CHMASS/MMASS                                                  MAIN
      XG=XA+XV(3)+XCH4                                                   MAIN
      XAIR(3)=XA                                                         MAIN
      XMETAN(3)=XCH4                                                     MAIN
      XGAS(3)=XG                                                         MAIN
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ MAIN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC MAIN
C                                                                      C MAIN
C REPEAT                                                               C MAIN
C                                                                      C MAIN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC MAIN
      IF(ISTAGE.EQ.NS) GO TO 902                                         MAIN
      GO TO 900                                                          MAIN
  902 OVALPR=P(3)/OP01                                                   MAIN
      OVALTR=TG(3)/OT01G                                                 MAIN
      GAMMAV=(GAMMAI+GAMMAO)/2.0                                         MAIN
      G4=(GAMMAV-1.0)/GAMMAV                                             MAIN
      OVALEF=(OVALPR**G4-1.0)/(OVALTR-1.0)                               MAIN
      ODELTG=TG(3)-OT01G                                                 MAIN
      ODELTW=0.0                                                         MAIN
      DELTWW=0.0                                                         MAIN
      DELMT=0.0                                                          MAIN
      DELMWT=0.0                                                         MAIN
      DELMG=0.0                                                          MAIN
      IF(XDIN.GT.0.0) ODELTW=TW(3)-OT01D                                 MAIN
      IF(XDDIN.GT.0.0) DELTWW=TWW(3)-OT01D                               MAIN
      DELMT=(MMASS-TLMO)/TLMO                                            MAIN
      IF(WTMO.GT.0.0) DELMWT=(WTMASS(3)-WTMO)/WTMO                       MAIN
      DELMG=(GMASS(3)-GMO)/GMO                                           MAIN
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ MAIN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC MAIN
C                                                                      C MAIN
C OUTPUT (OVERALL PERFORMANCE)                                          C MAIN
C                                                                      C MAIN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC MAIN
      CCMASS=CMASS*AAAR1T/AAAIGV                                         MAIN
      C2MASS=CMASS2*AAAR1T/AAAIGV                                        MAIN
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      IF(IUNIT.NE.2) GO TO 855
      TOG=TOG*CFT
      P0=P0*CFP
      CMASS=CMASS*CFM
      CCMASS=CCMASS*CFM
      CMASS2=CMASS2*CFM
      C2MASS=C2MASS*CFM
      ODELTG=ODELTG*CFT
  855 CONTINUE
      WRITE(6,421)
  421 FORMAT(1H1,≠********** OVERALL PERFORMANCE **********≠)
      WRITE(6,4220) FAIO
 4220 FORMAT(1H0,1X,≠INITIAL FLOW COEFFICIENT=≠,F7.5)
      WRITE(6,423) CRPM,FNF
  423 FORMAT(1H0,1X,≠CORRECTED SPEED=≠,F7.1,5X,F5.3,1X,
     $≠FRACTION OF DEIGN CORRECTED SPEED≠)
      WRITE(6,424)XDIN,XDDIN,XWTO,RHUMID,XCH4IN
  424 FORMAT(1H0,1X,≠INITIAL WATER CONTENT(SMALL DROPLET)=≠,F5.3,/,
     $2X,≠INITIAL WATER CONTENT(LARGE DROPLET)=≠,F5.3,/,
     $2X,≠INITIAL WATER CONTENT(TOTAL)=≠,F5.3,/,
     $2X,≠INITIAL RELATIVE HUMIDITY=≠,F5.1,1X,≠PER CENT≠,/,
     $2X,≠INITIAL METHANE CONTENT=≠,F5.3)
      WRITE(6,425) TOG
  425 FORMAT(1H0,1X,≠COMPRESSOR INLET TOTAL TEMPERATURE=≠,F8.2)
      WRITE(6,426) P0
  426 FORMAT(1H0,1X,≠COMPRESSOR INLET TOTAL PRESSURE=≠,F10.2)
      CCMASS=CMASS*AAAR1T/AAAIGV
      C2MASS=CMASS2*AAAR1T/AAAIGV
      WRITE(6,427)  CMASS,CCMASS
  427 FORMAT(1H0,1X,≠CORRECTED MASS FLOW RATE OF MIXTURE=≠,F6.3,
     $≠(≠,F6.3,≠)≠)
      WRITE(6,428)  CMASS2,C2MASS
  428 FORMAT(1H0,1X,≠CORRECTED MASS FLOW RATE OF GAS PHASE ≠,F6.3,
     $≠(≠,F6.3,≠)≠)
      WRITE(6,429) OVALPR
  429 FORMAT(1H0,1X,≠OVERALL TOTAL PRESSURE RATIO=≠,F6.4)
      WRITE(6,430) OVALTR
  430 FORMAT(1H0,1X,≠OVERALL TOTAL TEMPERATURE RATIO=≠,F6.4)
      WRITE(6,431) OVALEF
  431 FORMAT(1H0,1X,≠OVERALL ADIABATIC EFFICIENCY=≠,F6.4)
      WRITE(6,432) ODELTG
  432 FORMAT(1H0,1X,≠OVERALL TEMPERATURE RISE OF GAS PHASE=≠,F8.3)
      IF(IUNIT.NE.2) GO TO 856
      TOG=TOG/CFT
      P0=P0/CFP
      CMASS=CMASS/CFM
      CCMASS=CCMASS/CFM
      CMASS2=CMASS2/CFM
      C2MASS=C2MASS/CFM
      ODELTG=ODELTG/CFT
  856 CONTINUE
      GO TO 901
  998 STOP
      END
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                    C
C SUBROUTINE WICSPA                                                  C
C                                                                    C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE WICSPA(FAIO,ISTAGE,MMASS,ALFA1,WKDONE,DAVE, XDIN,ETA,
     $BETA1,BETA2,VZ,ALFA2,ALFA3,DELTG,DELTW,W1,W2,V1,V2,V3,AK1,AK3)
      REAL M,MMASS
      COMMON TD(7),IUNIT
      COMMON CFL,CFT,CFP,CFD,CFM,CFV,CFA
      COMMON JPERFM,RHOG(3),RERUP,RERLOW,RESUP,RESLOW
      COMMON PREB,RRTIP(8),SRTIP(8),AAA1,AAA2,AAA3,SAREA(6),SAREAS(7)
      COMMON P(3),TG(3),XA,XV(3),XCH4,XW(3),XWW(3),XWT(3),TW(3),TWW(3)
      COMMON OMEGS(7),OMEGR(6),GAPR(6),GAPS(6)
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      COMMON RRHUB(6) , RC(6) , RBLADE(6) , STAGER(6)                   WICSPA
      COMMON SRHUB(7) , SC(7) , SBLADE(7) , STAGES(7)                   WICSPA
      COMMON SIGUMR(6) , BET1SR(6) , BET2SR(6) , AINCSR(6) , ADEVSR(6)  WICSPA
      COMMON SIGUMS(7) , BET1SS(7) , BET2SS(7) , AINCSS(7) , ADEVSS(7)  WICSPA
      COMMON UTIPG(6),UTIP(6),UTIPD(6),UOU(6),UMEAN(6),UHUB(6),U(6),FAI WICSPA
      COMMON AREA(6),AREAS(7),UU2(6),UTIP2(6),UMEAN2(6),UHUB2(6),IPRINT WICSPA
      COMMON ICENT,IICENT,FMR1(6),FMA2(6),IDESIN,FAID                   WICSPA
      COMMON NS,NS1,RT(6),RM(6),RH(6),ST(6),SM(6),SH(6)                 WICSPA
      COMMON DSMASS,AAREA(7),AAREAS(7),PR12D(6),PR13D(6),ETARD(6)       WICSPA
      COMMON DR(6),DS(6),DEQR(6),DEQS(6),BLOCK(6),BLOCKS(7)             WICSPA
      COMMON BET1MR(6),BET2MR(6),BET1MS(7),BET2MS(7),RADI1(6),RADI2(6)  WICSPA
      DIMENSION RHOM(3),ETAA(8)                                         WICSPA
      CPW=1.0                                                           WICSPA
      RHOW=62.3                                                         WICSPA
      CALL WICPRP(XA,XV(1),XCH4,TG(1),RMIX,CPMIX,GAMMA,G1,G2,G3)        WICSPA
      RHOG(1)=P(1)/RMIX/TG(1)                                           WICSPA
      BMASS=MMASS                                                       WICSPA
      CALL WICMAC(ISTAGE,BMASS,TG(1),P(1),M,VZ,C,XWT(1),ALFA1,          WICSPA
     $RMIX,CPMIX,AREA(ISTAGE))                                          WICSPA
      ASPEED=C                                                          WICSPA
      RHOG(1)=(1.0+G2*M **2)**G3*RHOG(1)                                WICSPA
      RHOM(1)=1.0/((1.0-XWT(1))/RHOG(1)+XWT(1)/RHOW)                    WICSPA
      VZ=BMASS/RHOM(1)/AREA(ISTAGE)                                     WICSPA
      VZZ=VZ                                                            WICSPA
      FAI=VZ/UTIPG(ISTAGE)                                              WICSPA
      IF(IPRINT.EQ.2) WRITE(6,602) ISTAGE                               WICSPA
  602 FORMAT(1H1,1X,≠ROTER INLET  ISTAGE=≠,I2)                          WICSPA
      XG=XA+XV(1)+XCH4                                                  WICSPA
      IF(IPRINT.EQ.2) WRITE(6,601) ASPEED,RHOG(1),RHOM(1),XG,XWT(1),    WICSPA
     $RHOG(1),FAI,VZ,UTIP                                               WICSPA
  601 FORMAT(1H0,9(F12.5,1X))                                           WICSPA
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ WICSPA
C VELOCITY TRIANGLE                                                     WICSPA
      CALL WICVT(ISTAGE,ASPEED,ALFA1,VZ,V1,VS1,WS1,BETA1,W1,BETA2,      WICSPA
     $WS2,VS2,ALFA2,W2,V2,ALFA3,V3,AK1,AK3)                             WICSPA
      DELWS=WS1-WS2                                                     WICSPA
      IF(IPRINT.EQ.2) WRITE(6,605)                                      WICSPA
  605 FORMAT(1H0,1X,≠VEL TRI≠)                                          WICSPA
      IF(IPRINT.EQ.2) WRITE(6,606) ALFA1,VZ,V1,VS1,WS1,BETA1,W1,BETA2,  WICSPA
     $WS2,VS2                                                           WICSPA
  606 FORMAT(1H0,10(F12.5,1X))                                          WICSPA
      IF(IPRINT.EQ.2) WRITE(6,607) ALFA2,W2,V2,ALFA3,DELWS,V3           WICSPA
  607 FORMAT(1H ,6(F12.5,1X))                                           WICSPA
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ WICSPA
C PERFORMANCE CURVE                                                     WICSPA
      CALL WICSCC(FAI,SAI,ETA,TAU,ISTAGE)                               WICSPA
      ETAA(ISTAGE)=ETA                                                  WICSPA
      IF(SAI.GT.1.0.AND.ETA.GT.0.0) GO TO 203                           WICSPA
      IF(IPRINT.EQ.2) WRITE(6,204) ISTAGE,FAI,SAI,ETA,TAU               WICSPA
  204 FORMAT(1H0,≠FAI IS TOO BIG OR TOO SMALLE AT ISTAGE=≠,             WICSPA
     $I2,2X,4(F6.4,5X))                                                 WICSPA
      GO TO 901                                                         WICSPA
  203 DELT=TAU*TD(ISTAGE)*UOU(ISTAGE)                                   WICSPA
      DELHIN=WICCPA(TG(1))*DELT                                         WICSPA
      DELHM=DELHIN                                                      WICSPA
      DELHG=DELHM*(1.0-XW(1))                                           WICSPA
      DELHW=DELHM*XW(1)                                                 WICSPA
      DELHWW=0.0                                                        WICSPA
      DELTWW=0.0                                                        WICSPA
      CPG=CPMIX                                                         WICSPA
      DELTG=DELHG/CPG/(XV(1)+XA+XCH4)                                   WICSPA
      IF(XDIN.GT.0.0) GO TO 850                                         WICSPA
      DELTW=0.0                                                         WICSPA
      GO TO 851                                                         WICSPA
  850 DELTW=DELHW/CPW/XW(1)                                             WICSPA
  851 PRATIO=(DELTG/TG(1)*ETA+1.0)**G1                                  WICSPA
      P(3)=PRATIO*P(1)                                                  WICSPA
      P(2)=P(3)                                                         WICSPA
      TG(2)=TG(1)+DELTG                                                 WICSPA
      TW(2)=TW(1)+DELTW                                                 WICSPA
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      TG(3)=TG(2)
      TW(3)=TW(2)
      IF(IPRINT.EQ.2) WRITE(6,603)
  603 FORMAT(1H0,1X,≠PERFORMANCE CURVE≠)
      IF(IPRINT.EQ.2) WRITE(6,604) FAI,SAI,ETA,TAU,DELT,PRATIO,P(3),
     $DELHIN
  604 FORMAT(1H ,8(F12.5,1X))
      IF(IPRINT.EQ.2) WRITE(6,650) DELT,DELHM,DELHG,DELHW,DELTG,DELTW
  650 FORMAT(1H ,6(F12.5,1X))
  901 RETURN
      END
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C SUBROUTINE WICSCC                                                    C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE WICSCC(FAI,SAI,ETA,TAU,ISTAGE)
      X=FAI
      IF(ISTAGE.EQ.1) GO TO 11
      IF(ISTAGE.EQ.2) GO TO 12
      IF(ISTAGE.EQ.3) GO TO 13
      IF(ISTAGE.EQ.4) GO TO 14
      IF(ISTAGE.EQ.5) GO TO 15
      IF(ISTAGE.EQ.6) GO TO 16
   11 A1=26.456
      B1=-366.48033
      C1=2161.46222
      D1=-6670.16668
      E1=11405.55557
      F1=-10280.00001
      G1=3822.22223
      A2=-120.02
      B2=1599.02
      C2=-8730.12223
      D2=25068.33336
      E2=-39922.22228
      F2=33466.66671
      G2=-11555.55557
      A3=-0.34
      B3=0.226
      GO TO 200
   12 A1=-4.285
      B1=65.44567
      C1=-332.95889
      D1=907.0
      E1=-1375.55556
      F1=1093.33334
      G1=-355.55556
      A2=116.32
      B2=-1354.73334
      C2=6515.80003
      D2=-16503.33341
      E2=23266.66677
      F2=-17333.33341
      G2=5333.33336
      A3=-0.055
      B3=0.095
      GO TO 200
   13 A1=154.07500
      B1=-1761.37834
      C1=8374.33337
      D1=-21034.16676
      E1=29450.00013
      F1=-21800.00010
      G1=6666.66670
      A2=-492.54
      B2=5539.88003
      C2=-25815.48301
      D2=63806.66696
```

```
      E2=-88155.55596
      F2=64533.33363
      G2=-19555.55565
      A3=-0.1333333
      B3=0.1539999
      GO TO 200
   14 A1=75.43300
      B1=-860.65834
      C1=4090.41113
      D1=-10210.83338
      E1=14147.77784
      F1=-10333.33338
      G1=3111.11113
      A2=-1182.22001
      B2=13501.23673
      C2=-63739.07807
      D2=159216.66740
      E2=-221844.44546
      F2=163466.66741
      G2=-49777.77800
      A3=-0.04
      B3=0.092
      GO TO 200
   15 A1=-105.07400
      B1=1149.70467
      C1=-5143.83224
      D1=12189.83339
      E1=-16138.88897
      F1=11320.00006
      G1=-3288.88891
      A2=352.04
      B2=-3991.84002
      C2=18707.68897
      D2=-46346.66688
      E2=64088.88918
      F2=-46933.33355
      G2=14222.22229
      A3=-0.1066666
      B3=0.12999999
      GO TO 200
   16 A1=-110.32400
      B1=1282.14134
      C1=-6126.79558
      D1=15550.00007
      E1=-22068.88899
      F1=16586.66674
      G1=-5155.55558
      A2=-175.54
      B2=1836.93001
      C2=-7955.44448
      D2=18268.33342
      E2=-23411.11123
      F2=15866.66675
      G2=-4444.44447
      A3=-0.255
      B3=0.21375
  200 SAI=A1+B1*X+C1*X**2+D1*X**3+E1*X**4+F1*X**5+G1*X**6
      ETA=A2+B2*X+C2*X**2+D2*X**3+E2*X**4+F2*X**5+G2*X**6
      TAU=A3*X+B3
      RETURN
      END
C++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                    C
C SUBROUTINE WICSPB                                                  C
C                                                                    C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE WICSPB(FAIO,ISTAGE,MMASS,ALFA1,WKDONE,DAV,DELV,WMAS,N,
     $OMEGA1,OMEGA2,OMEGA3,OMEGA4,OMEGA5,OMEGA6,OMEGAT,
     $BETA1,BETA2,VZ,ALFA2,ALFA3,DELTG,DELTW,W1,W2,V1,V2,V3,AK1,AK2,
```

```
     $AK3)                                                               WICSPB
      REAL M,MMASS                                                       WICSPB
      COMMON TD(7),IUNIT                                                 WICSPB
      COMMON CFL,CFT,CFP,CFD,CFM,CFV,CFA                                 WICSPB
      COMMON JPERFM,RHOG(3),RERUP,RERLOW,RESUP,RESLOW                    WICSPB
      COMMON PREB,RRTIP(8),SRTIP(8),AAA1,AAA2,AAA3,SAREA(6),SAREAS(7)    WICSPB
      COMMON P(3),TG(3),XA,XV(3),XCH4,XW(3),XWW(3),XWT(3),TW(3),TWW(3)   WICSPB
      COMMON OMEGS(7),OMEGR(6),GAPR(6),GAPS(6)                           WICSPB
      COMMON RRHUB(6) , RC(6) , RBLADE(6) , STAGER(6)                    WICSPB
      COMMON SRHUB(7) , SC(7) , SBLADE(7) , STAGES(7)                    WICSPB
      COMMON SIGUMR(6) , BET1SR(6) , BET2SR(6) , AINCSR(6) , ADEVSR(6)   WICSPB
      COMMON SIGUMS(7) , BET1SS(7) , BET2SS(7) , AINCSS(7) , ADEVSS(7)   WICSPB
      COMMON UTIPG(6),UTIP(6),UTIPD(6),UOU(6),UMEAN(6),UHUB(6),U(6),FAI  WICSPB
      COMMON AREA(6),AREAS(7),UU2(6),UTIP2(6),UMEAN2(6),UHUB2(6),IPRINT  WICSPB
      COMMON ICENT,IICENT,FMR1(6),FMA2(6),IDESIN,FAID                    WICSPB
      COMMON NS,NS1,RT(6),RM(6),RH(6),ST(6),SM(6),SH(6)                  WICSPB
      COMMON DSMASS,AAREA(7),AAREAS(7),PR12D(6),PR13D(6),ETARD(6)        WICSPB
      COMMON DR(6),DS(6),DEQR(6),DEQS(6),BLOCK(6),BLOCKS(7)              WICSPB
      COMMON BET1MR(6),BET2MR(6),BET1MS(7),BET2MS(7),RADI1(6),RADI2(6)   WICSPB
      DIMENSION RHOM(3),ETAA(6)                                          WICSPB
      AJ=778.26                                                          WICSPB
      PAI=3.1415926                                                      WICSPB
      CPW=1.0                                                            WICSPB
      RHOW=62.3                                                          WICSPB
      GC=32.174                                                          WICSPB
      CALL WICPRP(XA,XV(1),XCH4,TG(1),RMIX,CPMIX,GAMMA,G1,G2,G3)         WICSPB
      GAMMA1=GAMMA                                                       WICSPB
      RHOG(1)=P(1)/RMIX/TG(1)                                            WICSPB
      BMASS=MMASS                                                        WICSPB
      AAA2=AREAS(ISTAGE)                                                 WICSPB
      AAA3=AREA(ISTAGE+1)                                                WICSPB
      IF(ISTAGE.EQ.NS) AAA3=AAA2                                         WICSPB
      CALL WICMAC(ISTAGE,BMASS,TG(1),P(1),M,VZ,C,XWT(1),ALFA1,           WICSPB
     $RMIX,CPMIX,AAA1)                                                   WICSPB
      ASPEED=C                                                           WICSPB
      ASPED1=ASPEED                                                      WICSPB
      RHOG(1)=(1.0+G2*M **2)**G3*RHOG(1)                                 WICSPB
      RHOM(1)=1.0/((1.0-XWT(1))/RHOG(1)+XWT(1)/RHOW)                     WICSPB
      VZ1=VZ                                                             WICSPB
      VZ2=VZ                                                             WICSPB
      FAI1=VZ1/UTIPG(ISTAGE)                                             WICSPB
      ALFA1R = ALFA1 * PAI / 180.0                                       WICSPB
      V1 = VZ / COS ( ALFA1R )                                           WICSPB
      VS1 = VZ * TAN ( ALFA1R )                                          WICSPB
      WS1 = U(ISTAGE)- VS1                                               WICSPB
      T = WS1 / VZ                                                       WICSPB
      BETA1R = ATAN ( T)                                                 WICSPB
      BETA1 = BETA1R * 180.0 / PAI                                       WICSPB
      TT = VZ **2 + WS1 **2                                              WICSPB
      W1 = SQRT ( TT )                                                   WICSPB
      AMACH1 = W1 / ASPEED                                               WICSPB
      AMAC1=V1/ASPEED                                                    WICSPB
      TS1=TG(1)/(1.0+G2*AMAC1**2)                                        WICSPB
      PS1=(TG(1)/TS1)**(-G1)*P(1)                                        WICSPB
      PREL1=(1.0+G2*AMACH1**2)**G1*PS1                                   WICSPB
      TREL1=(1.0+G2*AMACH1**2)*TS1                                       WICSPB
      JJJ=1                                                              WICSPB
 2000 VZ2AS=VZ                                                           WICSPB
      CALL WICGSL(OMEGR(ISTAGE),SIGUMR(ISTAGE),BET1SR(ISTAGE),BET2SR(IST WICSPB
     $AGE),AINCSR(ISTAGE),ADEVSR(ISTAGE),AMACH1,BETA1,DEQ,DEQN,SITACS,   WICSPB
     $SITACN,BET2N,OMEGAN,FMR1(ISTAGE),IDESIN,AK1,AK2,AK3,VZ1,VZ2AS,     WICSPB
     $U(ISTAGE),RADI1(ISTAGE),RADI2(ISTAGE))                             WICSPB
      IF(IPRINT.EQ.2) WRITE(6,190) OMEGR(ISTAGE),SIGUMR(ISTAGE),         WICSPB
     $BET1SR(ISTAGE),BET2SR(ISTAGE),AINCSR(ISTAGE),ADEVSR(ISTAGE),       WICSPB
     $AMACH1,BETA1,DEQ,DEQN,SITACS,SITACN,BET2N,OMEGAN                   WICSPB
  190 FORMAT(1H0,1X,14(F7.3,2X))                                         WICSPB
      DEQRR=DEQN                                                         WICSPB
      SITACR=SITACN                                                      WICSPB
      AINCIR=BETA1-BET1MR(ISTAGE)                                        WICSPB
      ADEVIR=BET2N-BET2MR(ISTAGE)                                        WICSPB
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      IF(IPRINT.EQ.2) WRITE(6,191) AINCIR,AINCSR(ISTAGE),ADEVIR,        WICSPB
     $ADEVUSR(ISTAGE)                                                   WICSPB
  191 FORMAT(1H0,1X,4(F7.3,2X))                                         WICSPB
      OMEGA1=OMEGAN                                                     WICSPB
      BETA2=BET2N                                                       WICSPB
      BETA2R=BETA2*PAI/180.0                                            WICSPB
      W2=VZ/COS(BETA2R)                                                 WICSPB
      UG=(W1+W2)/2.0                                                    WICSPB
      OMEGAP=0.0                                                        WICSPB
      IF(XW(1).GT.0.0)                                                  WICSPB
     $CALL WICSDL(RC(ISTAGE),SIGUMR(ISTAGE),BETA1,BETA2,UG,RHOG(1),     WICSPB
     $WMAS,AAA1,VZ,IPRINT,OMEGAP)                                       WICSPB
      OMEGA2=OMEGAP                                                     WICSPB
      DELP2=OMEGA2*0.5*RHOG(1)/GC*(W1**2)                               WICSPB
      OMEGA3=0.0                                                        WICSPB
      DELP3=0.0                                                         WICSPB
      BETA2R = BETA2 * PAI / 180.0                                      WICSPB
      JJ=1                                                              WICSPB
  200 VZAS=VZ                                                           WICSPB
      WS2 = VZ * TAN ( BETA2R )                                         WICSPB
      VS2 = UU2(ISTAGE) - WS2                                           WICSPB
      IF(VS2.LT.0.0) GO TO 999                                          WICSPB
      TTT=VS2/VZ                                                        WICSPB
      ALFA2R = ATAN ( TTT )                                             WICSPB
      ALFA2 = ALFA2R * 180.0 / PAI                                      WICSPB
      TTTT = VZ ** 2 + WS2 ** 2                                         WICSPB
      W2 = SQRT ( TTTT )                                                WICSPB
      TTTTT = VZ ** 2 + VS2 ** 2                                        WICSPB
      V2 = SQRT ( TTTTT )                                               WICSPB
      DELH=WKDONE*(UU2(ISTAGE)*VS2-U(ISTAGE)*VS1)/GC/AJ                 WICSPB
      XG=1.0-XWT(1)                                                     WICSPB
      CALL WICIRS(ISTAGE,RRTIP(ISTAGE),XW(1),XG,RHOG(1),BETA1,W1,WW1,   WICSPB
     $WW2,WW)                                                           WICSPB
      AMIMPR=WW                                                         WICSPB
      IF(AMIMPR.GT.WMAS) AMIMPR=WMAS                                    WICSPB
      PREB=50.0                                                         WICSPB
      AMREBR=AMIMPR*PREB/100.0                                          WICSPB
      AMWAKR=AMIMPR*(1.0-PREB/100.0)                                    WICSPB
      AMNOIR=WMAS-AMIMPR                                                WICSPB
      XWNOIR=AMNOIR/MMASS                                               WICSPB
      XWREBR=AMREBR/MMASS                                               WICSPB
      XWWAKR=AMWAKR/MMASS                                               WICSPB
      XW1=0.0                                                           WICSPB
      XW2=0.0                                                           WICSPB
      XW3=0.0                                                           WICSPB
      IF(WMAS.GT.0.0) XW1=AMNOIR/WMAS                                   WICSPB
      IF(WMAS.GT.0.0) XW2=AMWAKR/WMAS                                   WICSPB
      IF(WMAS.GT.0.0) XW3=AMREBR/WMAS                                   WICSPB
      DELTG=DELH/CPMIX                                                  WICSPB
      DELTW1=DELH/CPW                                                   WICSPB
      DELTW2=DELH/CPW                                                   WICSPB
      DELTW3=0.0                                                        WICSPB
      DELTW=XW1*DELTW1+XW2*DELTW2+XW3*DELTW3                            WICSPB
      TW(2)=TW(1)+DELTW                                                 WICSPB
      TG(2)=TG(1)+DELTG                                                 WICSPB
      TS2=TG(2)-V2**2/(2.0*CPMIX*GC*AJ)                                 WICSPB
      AG2=(GAMMA*RMIX*TS2*GC)**0.5                                      WICSPB
      ASPEED=WICASD(XWT(1),RHOG(1),AG2)                                 WICSPB
      AMAC2=V2/ASPEED                                                   WICSPB
      AMACH2=W2/ASPEED                                                  WICSPB
      PP1=GAMMA*RMIX*TREL1*GC                                           WICSPB
      PP2=(UU2(ISTAGE)/U(ISTAGE))**2-1.0                                WICSPB
      PP3=1.0+G2*U(ISTAGE)**2/PP1*PP2                                   WICSPB
      PP=PP3**G1                                                        WICSPB
      PRREL=PP-(OMEGA1+OMEGA2+OMEGA3)*(1.0-PS1/PREL1)                   WICSPB
      PR12=(TG(2)/TG(1))**G1*PRREL/PP                                   WICSPB
      P(2)=PR12*P(1)                                                    WICSPB
      PS2=(1.0+G2*AMAC2**2)**(-G1)*P(2)                                 WICSPB
      RHOG2=PS2/RMIX/TS2                                                WICSPB
      RHOG(2)=RHOG2                                                     WICSPB
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```
      RHOM2=1.0/(XG/RHOG2+XWT(1)/RHOW)
      VZ=BMASS/RHOM2/AAA2
      VZ2=VZ
      EPS=1.0E-4
      IF(JJ.EQ.2) GO TO 201
      IF(JJ.GT.2) GO TO 202
      X1=VZAS
      Y1=VZ2
      VZ=VZ2
      JJ=JJ+1
      GO TO 200
  201 X2=VZAS
      Y2=VZ2
      VZ=WICNEW(X1,Y1,X2,Y2)
      IF(IPRINT.EQ.2) WRITE(6,203) JJ,VZ
  203 FORMAT(1H ,1X,I1,2X,≠VZ2=≠,F10.5)
      JJ=JJ+1
      IF(VZ.LT.0.0.OR.VZ.GT.ASPEED) GO TO 999
      GO TO 200
  202 IF(ABS((VZAS-VZ2)/VZAS).LT.EPS) GO TO 300
      X1=X2
      Y1=Y2
      X2=VZAS
      Y2=VZ2
      VZ=WICNEW(X1,Y1,X2,Y2)
      IF(IPRINT.EQ.2) WRITE(6,204) JJ,VZ
  204 FORMAT(1H0,1X,I1,2X,≠VZ2=≠,F10.5)
      JJ=JJ+1
      IF(VZ.LT.0.0.OR.VZ.GT.ASPEED) GO TO 999
      IF(JJ.EQ.20) GO TO 300
      GO TO 200
  300 VZ2CL=VZ
      IF(JJJ.EQ.2) GO TO 2010
      IF(JJJ.GT.2) GO TO 2020
      XX1=VZ2AS
      YY1=VZ2CL
      JJJ=JJJ+1
      GO TO 2000
 2010 XX2=VZ2AS
      YY2=VZ2CL
      VZ=WICNEW(XX1,YY1,XX2,YY2)
      IF(IPRINT.EQ.2) WRITE(6,2030) JJJ,VZ
 2030 FORMAT(1H ,1X,I2,≠VZ22=≠,F10.5)
      JJJ=JJJ+1
      GO TO 2000
 2020 IF(ABS((VZ2AS-VZ2CL)/VZ2AS).LT.EPS) GO TO 3000
      XX1=XX2
      YY1=YY2
      XX2=VZ2AS
      YY2=VZ2CL
      VZ=WICNEW(XX1,YY1,XX2,YY2)
      IF(IPRINT.EQ.2) WRITE(6,2040) JJJ,VZ
 2040 FORMAT(1H ,1X,I2,≠VZ22=≠,F10.5)
      JJJ=JJJ+1
      IF(JJJ.EQ.20) GO TO 3000
      GO TO 2000
 3000 VZ2=VZ2CL
      FAI2=VZ2/UTIPG(ISTAGE)
      P(2)=(1.0+G2*AMAC2**2)**G1*PS2
      JJJJ=1
 3001 VZ3AS=VZ
      CALL WICGSL(OMEGS(ISTAGE),SIGUMS(ISTAGE),BET1SS(ISTAGE),
     $BET2SS(ISTAGE),AINCSS(ISTAGE),ADEVSS(ISTAGE),AMAC2,ALFA2,DEQS,
     $DEQN,SITACS,SITACN,BET2N,OMEGAN,FMA2(ISTAGE),IDESIN,AK1,AK2,AK3,
     $VZ2,VZ3AS,0.0,RADI2(ISTAGE),RADI1(ISTAGE+1))
      ASPED2=ASPEED
      DEQSS=DEQN
      SITACS=SITACN
      AINCIS=ALFA2-BET1MS(ISTAGE)
      ADEVIS=BET2N-BET2MS(ISTAGE)
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      IF(IPRINT.EQ.2) WRITE(6,302) AINCIS,AINCSS(ISTAGE),ADEVIS,
     $ADEVSS(ISTAGE)
  302 FORMAT(1H0,1X,4(F7.3,2X))
      OMEGA4=OMEGAN
      ALFA3=BET2N
      ALFA3R=ALFA3*PAI/180.0
      V3=VZ/COS(ALFA3R)
      UG=(V2+V3)/2.0
      OMEGAP=0.0
      IF(XW(1).GT.0.0)
     $CALL WICSDL(SC(ISTAGE),SIGUMS(ISTAGE),ALFA2,ALFA3,UG,RHOG(2)
     $,WMAS,AAA2,VZ,IPRINT,OMEGAP)
      OMEGA5=OMEGAP
      DELP5=OMEGA5*0.5*RHOG(2)/GC*(V2**2)
      DELP6=0.0
      OMEGA6=0.0
      PR23=1.0-(OMEGA4+OMEGA5+OMEGA6)*(1.0-PS2/P(2))
      PR13I=(TG(2)/TG(1))**G1
      PR13=(TG(2)/TG(1))**G1*PRREL*PR23/PP
      P(3)=PR13*P(1)
      TG(3)=TG(2)
      TS3=TG(3)-V3**2/(2.0*CPMIX*GC*AJ)
      AG3=(GAMMA*RMIX*TS3*GC)**0.5
      ASPEED=WICASD(XWT(1),RHOG(2),AG3)
      ASPED3=ASPEED
      AMAC3=V3/ASPEED
      PS3=(1.0+G2*AMAC3**2)**(-G1)*P(3)
      RHOG3=PS3/RMIX/TS3
      RHOG(3)=RHOG3
      RHOM3=1.0/(XG/RHOG3+XWT(1)/RHOW)
      VZ=BMASS/RHOM3/AAA3
      VZ3CL=VZ
      IF(JJJJ.EQ.2) GO TO 3010
      IF(JJJJ.GT.2) GO TO 3020
      XXX1=VZ3AS
      YYY1=VZ3CL
      JJJJ=JJJJ+1
      GO TO 3001
 3010 XXX2=VZ3AS
      YYY2=VZ3CL
      VZ=WICNEW(XXX1,YYY1,XXX2,YYY2)
      IF(IPRINT.EQ.2) WRITE(6,3030) JJJJ,VZ
 3030 FORMAT(1H ,1X,I2,2X,≠VZ33=≠,F10.5)
      JJJJ=JJJJ+1
      GO TO 3001
 3020 IF(ABS((VZ3AS-VZ3CL)/VZ3AS).LT.EPS) GO TO 4000
      XXX1=XXX2
      YYY1=YYY2
      XXX2=VZ3AS
      YYY2=VZ3CL
      VZ=WICNEW(XXX1,YYY1,XXX2,YYY2)
      IF(IPRINT.EQ.2) WRITE(6,3040) JJJJ,VZ
 3040 FORMAT(1H ,1X,I2,≠VZ33=≠,F10.5)
      JJJJ=JJJJ+1
      IF(JJJJ.EQ.20) GO TO 999
      GO TO 3001
 4000 VZ3=VZ3CL
      FAI3=VZ3/UTIPG(ISTAGE+1)
      TW(3)=TW(2)
      OMEGTR=OMEGA1+OMEGA2+OMEGA3
      OMEGTS=OMEGA4+OMEGA5+OMEGA6
      POMEG1=OMEGA1/OMEGTR*100.0
      POMEG2=OMEGA2/OMEGTR*100.0
      POMEG3=OMEGA3/OMEGTR*100.0
      POMEG4=OMEGA4/OMEGTS*100.0
      POMEG5=OMEGA5/OMEGTS*100.0
      POMEG6=OMEGA6/OMEGTS*100.0
      PRATIO=P(3)/P(1)
      TRATIO=TG(3)/TG(1)
      CALL WICPRP(XA,XV(3),XCH4,TG(3),RMIX,CPMIX,GAMMA,G1,G2,G3)
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      GAMMA2=GAMMA                                                      WICSPB
      GAMMAV=(GAMMA1+GAMMA2)/2.0                                        WICSPB
      G4=(GAMMAV-1.0)/GAMMAV                                            WICSPB
      ETAA(ISTAGE)=(PRATIO**G4-1.0)/(TRATIO-1.0)                        WICSPB
      IF(IUNIT.NE.2) GO TO 857                                          WICSPB
      UTIPG(ISTAGE)=UTIPG(ISTAGE)*CFV                                   WICSPB
      P(1)=P(1)*CFP                                                     WICSPB
      P(2)=P(2)*CFP                                                     WICSPB
      P(3)=P(3)*CFP                                                     WICSPB
      PS1=PS1*CFP                                                       WICSPB
      PS2=PS2*CFP                                                       WICSPB
      PS3=PS3*CFP                                                       WICSPB
      TG(1)=TG(1)*CFT                                                   WICSPB
      TG(2)=TG(2)*CFT                                                   WICSPB
      TG(3)=TG(3)*CFT                                                   WICSPB
      TS1=TS1*CFT                                                       WICSPB
      TS2=TS2*CFT                                                       WICSPB
      TS3=TS3*CFT                                                       WICSPB
      RHOG(1)=RHOG(1)*CFD                                               WICSPB
      RHOG2=RHOG2*CFD                                                   WICSPB
      RHOG3=RHOG3*CFD                                                   WICSPB
      RHOM(1)=RHOM(1)*CFD                                               WICSPB
      RHOM2=RHOM2*CFD                                                   WICSPB
      RHOM3=RHOM3*CFD                                                   WICSPB
      VZ1=VZ1*CFV                                                       WICSPB
      VZ2=VZ2*CFV                                                       WICSPB
      VZ3=VZ3*CFV                                                       WICSPB
      V1=V1*CFV                                                         WICSPB
      V2=V2*CFV                                                         WICSPB
      V3=V3*CFV                                                         WICSPB
      W1=W1*CFV                                                         WICSPB
      W2=W2*CFV                                                         WICSPB
      U(ISTAGE)=U(ISTAGE)*CFV                                           WICSPB
      UU2(ISTAGE)=UU2(ISTAGE)*CFV                                       WICSPB
      U(ISTAGE+1)=U(ISTAGE+1)*CFV                                       WICSPB
      VS1=VS1*CFV                                                       WICSPB
      VS2=VS2*CFV                                                       WICSPB
      WS1=WS1*CFV                                                       WICSPB
      WS2=WS2*CFV                                                       WICSPB
      ASPED1=ASPED1*CFV                                                 WICSPB
      ASPED2=ASPED2*CFV                                                 WICSPB
      ASPED3=ASPED3*CFV                                                 WICSPB
      AAA1=AAA1*CFA                                                     WICSPB
      AAA2=AAA2*CFA                                                     WICSPB
      AAA3=AAA3*CFA                                                     WICSPB
  857 CONTINUE                                                          WICSPB
      WRITE(6,404) FAI0,ISTAGE                                          WICSPB
  404 FORMAT(1H1,1X,≠********************  ≠,1X,                        WICSPB
     $≠INITIAL FLOW COEFFICIENT=≠,1X,F7.5,1X,≠(STAGE=≠,I2,1X,           WICSPB
     $≠)≠,2X,≠********************≠)                                    WICSPB
       WRITE(6,401) PRATIO,TRATIO,ETAA(ISTAGE)                          WICSPB
  401 FORMAT(1H0,5X,≠STAGE TOTAL PRESSURE RATIO=≠,F12.5,/,              WICSPB
     $6X,≠STAGE TOTAL TEMPERATURE RATIO=≠,F12.5,/,                      WICSPB
     $6X,≠STAGE ADIABATIC EFFICIENCY=≠,F12.5)                           WICSPB
       WRITE(6,402) FAI1,VZ1,UTIPG(ISTAGE)                              WICSPB
  402 FORMAT(1H0,5X,≠STAGE FLOW COEFFICIENT=≠,F5.3,/,                   WICSPB
     $6X,≠AXIAL VELOCITY=≠,F7.2,/,                                      WICSPB
     $6X,≠ROTOR SPEED=≠,F7.2,/)                                         WICSPB
      WRITE(6,403) PR13,PR13I,PRREL,PR23                                WICSPB
  403 FORMAT(1H ,5X,≠STAGE TOTAL PRESSURE RATIO(ACTUAL)=≠,F12.5,/,      WICSPB
     $6X,≠STAGE TOTAL PRESSURE RATIO(IDEAL)=≠,F12.5,/,                  WICSPB
     $6X,≠LOSS FACTOR IN ROTOR=≠,F12.5,/,                               WICSPB
     $6X,≠LOSS FACTOR IN STATOR=≠,F12.5,/)                              WICSPB
      WRITE(6,405)                                                      WICSPB
  405 FORMAT(1H0,24X,≠*ROTOR INLET* *ROTOR OUTLET* *STATOR OUTLET*≠)    WICSPB
      WRITE(6,406) P(1),P(2),P(3)                                       WICSPB
  406 FORMAT(1H ,1X,≠TOTAL PRESSURE≠,10X,3(F10.2,5X))                   WICSPB
      WRITE(6,407) PS1,PS2,PS3                                          WICSPB
  407 FORMAT(1H ,1X,≠STATIC PRESSURE≠,9X,3(F10.2,5X))                   WICSPB
      WRITE(6,408) TG(1),TG(2),TG(3)                                    WICSPB
```

```
  408 FORMAT(1H ,1X,≠TOTAL TEMPERATURE(GAS)≠,3X,3(F10.4,5X))
      WRITE(6,409) TS1,TS2,TS3
  409 FORMAT(1H ,1X,≠STATIC TEMPERATURE(GAS)≠,1X,3(F10.4,5X))
      WRITE(6,410) RHOG(1),RHOG2,RHOG3
  410 FORMAT(1H ,1X,≠STATIC DENSITY(GAS)≠,5X,3(F10.4,5X))
      WRITE(6,411) RHOM(1),RHOM2,RHOM3
  411 FORMAT(1H ,1X,≠STATIC DENSITY(MIXTURE)≠,1X,3(F10.4,5X))
      WRITE(6,412) VZ1,VZ2,VZ3
  412 FORMAT(1H0,1X,≠AXIAL VELOCITY≠,10X,3(F10.4,5X))
      WRITE(6,413) V1,V2,V3
  413 FORMAT(1H ,1X,≠ABSOLUTE VELOCITY≠,7X,3(F10.4,5X))
      WRITE(6,414) W1,W2
  414 FORMAT(1H ,1X,≠RELATIVE VELOCITY≠,7X,2(F10.4,5X))
      WRITE(6,415) U(ISTAGE),UU2(ISTAGE),U(ISTAGE+1)
  415 FORMAT(1H ,1X,≠BLADE SPEED≠,13X,3(F10.4,5X))
      WRITE(6,416) VS1,VS2
  416 FORMAT(1H ,1X,≠TANG. COMP. OF ABS. VEL.≠,2(F10.4,5X))
      WRITE(6,417) WS1,WS2
  417 FORMAT(1H ,1X,≠TANG. COMP. OF REL. VEL.≠,2(F10.4,5X))
      WRITE(6,418) ASPED1,ASPED2,ASPED3
  418 FORMAT(1H ,1X,≠ACOUSTIC SPEED≠,10X,3(F10.4,5X))
      WRITE(6,419) AMAC1,AMAC2,AMAC3
  419 FORMAT(1H ,1X,≠ABSOLUTE MACH NUMBER≠,4X,3(F10.4,5X))
      WRITE(6,420) AMACH1,AMACH2
  420 FORMAT(1H ,1X,≠RELATIVE MACH NUMBER≠,4X,2(F10.4,5X))
      WRITE(6,421) FAI1,FAI2,FAI3
  421 FORMAT(1H0,1X,≠FLOW COEFFICIENT≠,8X,3(F10.4,5X))
      WRITE(6,422) AAA1,AAA2,AAA3
  422 FORMAT(1H ,1X,≠FLOW AREA≠,15X,3(F10.4,5X))
      WRITE(6,423) ALFA1,ALFA2,ALFA3
  423 FORMAT(1H0,1X,≠ABSOLUTE FLOW ANGLE≠,5X,3(F10.4,5X))
      WRITE(6,424) BETA1,BETA2
  424 FORMAT(1H ,1X,≠RELATIVE FLOW ANGLE≠,5X,3(F10.4,5X))
      WRITE(6,425) AINCIR,AINCIS
  425 FORMAT(1H ,1X,≠INCIDENCE≠,16X,2(F10.4,5X))
      WRITE(6,426) ADEVIR,ADEVIS
  426 FORMAT(1H ,1X,≠DEVIATION≠,30X,2(F10.4,5X))
      IF(IUNIT.NE.2) GO TO 858
      UTIPG(ISTAGE)=UTIPG(ISTAGE)/CFV
      P(1)=P(1)/CFP
      P(2)=P(2)/CFP
      P(3)=P(3)/CFP
      PS1=PS1/CFP
      PS2=PS2/CFP
      PS3=PS3/CFP
      TG(1)=TG(1)/CFT
      TG(2)=TG(2)/CFT
      TG(3)=TG(3)/CFT
      TS1=TS1/CFT
      TS2=TS2/CFT
      TS3=TS3/CFT
      RHOG(1)=RHOG(1)/CFD
      RHOG2=RHOG2/CFD
      RHOG3=RHOG3/CFD
      RHOM(1)=RHOM(1)/CFD
      RHOM2=RHOM2/CFD
      RHOM3=RHOM3/CFD
      VZ1=VZ1/CFV
      VZ2=VZ2/CFV
      VZ3=VZ3/CFV
      V1=V1/CFV
      V2=V2/CFV
      V3=V3/CFV
      W1=W1/CFV
      W2=W2/CFV
      U(ISTAGE)=U(ISTAGE)/CFV
      UU2(ISTAGE)=UU2(ISTAGE)/CFV
      U(ISTAGE+1)=U(ISTAGE+1)/CFV
      VS1=VS1/CFV
      VS2=VS2/CFV
```

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      WS1=WS1/CFV
      WS2=WS2/CFV
      ASPED1=ASPED1/CFV
      ASPED2=ASPED2/CFV
      ASPED3=ASPED3/CFV
      AAA1=AAA1/CFA
      AAA2=AAA2/CFA
      AAA3=AAA3/CFA
  858 CONTINUE
  999 RETURN
      END
C++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                    C
C SUBROUTINE WICSPC                                                  C
C                                                                    C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE WICSPC(FAIO,ISTAGE,MMASS,ALFA1,WKDONE,DAV,DELV,WMAS,
     $WWMAS,N,
     $OMEGA1,OMEGA2,OMEGA3,OMEGA4,OMEGA5,OMEGA6,OMEGAT,
     $BETA1,BETA2,VZ,ALFA2,ALFA3,DELTG,DELTW,W1,W2,V1,V2,V3,REAVE,
     $DELVU2,DELVL2,AK1,AK2,AK3)
      REAL M,MMASS
      COMMON TD(7),IUNIT
      COMMON CFL,CFT,CFP,CFD,CFM,CFV,CFA
      COMMON JPERFM,RHOG(3),RERUP,RERLOW,RESUP,RESLOW
      COMMON PREB,RRTIP(8),SRTIP(8),AAA1,AAA2,AAA3,SAREA(6),SAREAS(7)
      COMMON P(3),TG(3),XA,XV(3),XCH4,XW(3),XWW(3),XWT(3),TW(3),TWW(3)
      COMMON OMEGS(7),OMEGR(6),GAPR(6),GAPS(6)
      COMMON RRHUB(6) , RC(6) , RBLADE(6) , STAGER(6)
      COMMON SRHUB(7) , SC(7) , SBLADE(7) , STAGES(7)
      COMMON SIGUMR(6) , BET1SR(6) , BET2SR(6) , AINCSR(6) , ADEVSR(6)
      COMMON SIGUMS(7) , BET1SS(7) , BET2SS(7) , AINCSS(7) , ADEVSS(7)
      COMMON UTIPG(6),UTIP(6),UTIPD(6),UOU(6),UMEAN(6),UHUB(6),U(6),FAI
      COMMON AREA(6),AREAS(7),UU2(6),UTIP2(6),UMEAN2(6),UHUB2(6),IPRINT
      COMMON ICENT,IICENT,FMR1(6),FMA2(6),IDESIN,FAID
      COMMON NS,NS1,RT(6),RM(6),RH(6),ST(6),SM(6),SH(6)
      COMMON DSMASS,AAREA(7),AAREAS(7),PR12D(6),PR13D(6),ETARD(6)
      COMMON DR(6),DS(6),DEQR(6),DEQS(6),BLOCK(6),BLOCKS(7)
      COMMON BET1MR(6),BET2MR(6),BET1MS(7),BET2MS(7),RADI1(6),RADI2(6)
      DIMENSION RHOM(3),ETAA(6)
      IPRINT=1
      CPW=1.0
      RHOW=62.3
      GC=32.174
      AJ=778.26
      PAI=3.1415926
      CALL WICPRP(XA,XV(1),XCH4,TG(1),RMIX,CPMIX,GAMMA,G1,G2,G3)
      GAMMA1=GAMMA
      RHOG(1)=P(1)/RMIX/TG(1)
      BMASS=MMASS-WMAS-WWMAS
      AAA2=AREAS(ISTAGE)
      AAA3=AREA(ISTAGE+1)
      IF(ISTAGE.EQ.NS) AAA3=AAA2
      CALL WICMAC(ISTAGE,BMASS,TG(1),P(1),M,VZ,C,XWT(1),ALFA1,
     $RMIX,CPMIX,AAA1)
      ASPEED=C
      ASPED1=ASPEED
      RHOG(1)=(1.0+G2*M **2)**G3*RHOG(1)
      RHOM(1)=1.0/((1.0-XWT(1))/RHOG(1)+XWT(1)/RHOW)
      VZ1=VZ
      VZ2=VZ
      FAI1=VZ1/UTIPG(ISTAGE)
      ALFA1R = ALFA1 * PAI / 180.0
      V1 = VZ / COS ( ALFA1R )
      VS1 = VZ * TAN ( ALFA1R )
      WS1 = U(ISTAGE)- VS1
      T = WS1 / VZ
      BETA1R = ATAN ( T)
      BETA1 = BETA1R * 180.0 / PAI
```

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      TT = VZ **2 + WS1 **2
      W1 = SQRT ( TT )
      AMACH1 = W1 / ASPEED
      AMAC1=V1/ASPEED
      TS1=TG(1)/(1.0+G2*AMAC1**2)
      PS1=(TG(1)/TS1)**(-G1)*P(1)
      PREL1=(1.0+G2*AMACH1**2)**G1*PS1
      TREL1=(1.0+G2*AMACH1**2)*TS1
      TG(2)=TG(1)
      P(2)=P(1)
      ALFA2=BET1SS(ISTAGE)
      JJJ=1
 2000 VZ2AS=VZ
      CALL WICGSL(OMEGR(ISTAGE),SIGUMR(ISTAGE),BET1SR(ISTAGE),BET2SR(
     $ISTAGE),AINCSR(ISTAGE),ADEVSR(ISTAGE),AMACH1,BETA1,DEQS,DEQN,
     $SITACS,SITACN,BET2N,OMEGAN,FMR1(ISTAGE),IDESIN,AK1,AK2,AK3,VZ1,
     $VZ2AS,U(ISTAGE),RADI1(ISTAGE),RADI2(ISTAGE))
      OMEGA7=OMEGAN
      BETA2=BET2N
      BETA1R=BETA1*PAI/180.0
      BETA2R=BETA2*PAI/180.0
      BETAVE=(BETA1R+BETA2R)/2.0
      TANGT=WICTAN(BETA1R)-WICTAN(BETA2R)
      CSAV=COS(BETAVE)
      CS1=COS(BETA1R)
      CL=2.0/SIGUMR(ISTAGE)*TANGT*CSAV
      CDS=0.018*(CL**2)
      OMEGSE=CDS*SIGUMR(ISTAGE)*(CS1**2)/(CSAV**3)
      H=RRTIP(ISTAGE)-RRHUB(ISTAGE)
      SHR=RC(ISTAGE)/H/SIGUMR(ISTAGE)
      CDA=0.020*SHR
      OMEGAN=CDA*SIGUMR(ISTAGE)*(CS1**2)/(CSAV**3)
      IF(IPRINT.EQ.2) WRITE(6,2001) OMEGA1,OMEGSE,OMEGAN,OMEGA7,CDS,CDA
 2001 FORMAT(1H0,6F10.6)
      OMES1=OMEGSE
      OMEA1=OMEGAN
      AINCIR=BETA1-BET1MR(ISTAGE)
      ADEVIR=BET2N-BET2MR(ISTAGE)
      BETA2R=BETA2*PAI/180.0
      W2=VZ/COS(BETA2R)
      UG=(W1+W2)/2.0
      CALL WICRSL(SIGUMR(ISTAGE),BETA1,BETA2,RC(ISTAGE),DAV,CDR,OMEGAR)
      DELP1=OMEGA1*0.5*RHOG(1)/GC*(W1**2)
      IF(IPRINT.EQ.2) WRITE(6,2002) OMEGA1,DELP1
 2002 FORMAT(1H ,1X,≠OMEGA1=≠,2F10.5)
      XG=1.0-XWT(1)
      CALL WICIRL(ISTAGE,RRTIP(ISTAGE),XWW(1),XG,RHOG(1),BETA1,W1,WW1,WW
     $2,WW)
      BMIMPR=WW
      IF(BMIMPR.GT.WWMAS) BMIMPR=WWMAS
      BMREBR=BMIMPR*PREB/100.0
      BMWAKR=BMIMPR*(1.0-PREB/100.0)
      BMNOIR=WWMAS-BMIMPR
      XWWNOR=BMNOIR/MMASS
      XWWRER=BMREBR/MMASS
      XWWWAR=BMWAKR/MMASS
      IF(IPRINT.EQ.2) WRITE(6,6090) BMIMPR,BMREBR,BMWAKR,BMNOIR,XWWNOR,
     $XWWRER,XWWWAR
 6090 FORMAT(1H ,7(F12.5,1X))
      RST1=RADI1(ISTAGE)**2-AAA1*144.0/2.0/PAI
      RST1=SQRT(RST1)
      RST2=2.0*RADI1(ISTAGE)**2-RST1**2
      RST2=SQRT(RST2)
      DELR=(RST2-RST1)/12.0
      FMASSR=BMWAKR/DELR
      CALL WICFML(W1,W2,FMASSR,RHOG(1),RC(ISTAGE),SIGUMR(ISTAGE),BETA1,
     $BETA2,CDF,OMEGAF)
      OMEGA2=OMEGAF
      DELP2=OMEGA2*0.5*RHOG(1)/GC*(W1**2)
      IF(IPRINT.EQ.2) WRITE(6,6091) OMEGA2,DELP2
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6091 FORMAT(1H ,1X,≠OMEGA2=≠,2F10.5)
     V2=0.0
     V3=0.0
     ALFA=0.0
     ALFA3=0.0
     CALL WICSTL(ISTAGE,1,DAV,W1,W2,DELV,V2,V3,WWMAS,VZ,N,BETA1,BETA2,
    $ALFA2,ALFA3,BMASS,DELVU2,DELVL2,OMEGRU,OMEGRL,OMEGSU,OMEGSL,
    $DRAGRU,DRAGRL,DRAGSU,DRAGSL,REAVE)
     OMEGA3=OMEGRU+OMEGRL
     DELP3=OMEGA3*0.5*RHOG(1)/GC*(W1**2)
     IF(IPRINT.EQ.2) WRITE(6,6092) OMEGA3,DELP3
6092 FORMAT(1H ,1X,≠OMEGA3=≠,2F10.5)
     REAVE1=REAVE
     BETA2R = BETA2 * PAI / 180.0
     JJ=1
 200 VZAS=VZ
     WS2 = VZ * TAN ( BETA2R )
     VS2 = UU2(ISTAGE) - WS2
     TTT=VS2/VZ
     ALFA2R = ATAN ( TTT )
     ALFA2 = ALFA2R * 180.0 / PAI
     TTTT = VZ ** 2 + WS2 ** 2
     W2 = SQRT ( TTTT )
     TTTTT = VZ ** 2 + VS2 ** 2
     V2 = SQRT ( TTTTT )
     DELH=WKDONE*(UU2(ISTAGE)*VS2-U(ISTAGE)*VS1)/GC/AJ
     CALL WICIRS(ISTAGE,RRTIP(ISTAGE),XW(1),XG,RHOG(1),BETA1,W1,WW1,
    $WW2,WW)
     AMIMPR=WW
     IF(AMIMPR.GT.WMAS) AMIMPR=WMAS
     PREB=50.0
     AMREBR=AMIMPR*PREB/100.0
     AMWAKR=AMIMPR*(1.0-PREB/100.0)
     AMNOIR=WMAS-AMIMPR
     XW1=0.0
     XW2=0.0
     XW3=0.0
     IF(WMAS.GT.0.0) XW1=AMNOIR/WMAS
     IF(WMAS.GT.0.0) XW2=AMWAKR/WMAS
     IF(WMAS.GT.0.0) XW3=AMREBR/WMAS
     DELTG=DELH/CPMIX
     DELTW1=DELH/CPW
     DELTW2=DELH/CPW
     DELTW3=0.0
     DELTW=XW1*DELTW1+XW2*DELTW2+XW3*DELTW3
     DETWW1=0.0
     DETWW2=0.0
     DETWW3=0.0
     DELTWW=0.0
     TW(2)=TW(1)+DELTW
     TWW(2)=TWW(1)+DELTWW
     TG(2)=TG(1)+DELTG
     TS2=TG(2)-V2**2/(2.0*CPMIX*GC*AJ)
     AG2=(GAMMA*RMIX*TS2*GC)**0.5
     ASPEED=WICASD(XWT(1),RHOG(1),AG2)
     ASPED2=ASPEED
     AMAC2=V2/ASPEED
     AMACH2=W2/ASPEED
     PP1=GAMMA*RMIX*TREL1*GC
     PP2=(UU2(ISTAGE)/U(ISTAGE))**2-1.0
     PP3=1.0+G2*U(ISTAGE)**2/PP1*PP2
     PP=PP3**G1
     PRREL=PP-(OMEGA7+OMEGA1+OMEGA2+OMEGA3)*(1.0-PS1/PREL1)
     PR12=(TG(2)/TG(1))**G1*PRREL/PP
     P(2)=PR12*P(1)
     PS2=(1.0+G2*AMAC2**2)**(-G1)*P(2)
     RHOG2=PS2/RMIX/TS2
     RHOG(2)=RHOG2
     RHOM2=1.0/(XG/RHOG2+XWT(1)/RHOW)
     VZ=BMASS/RHOG2/AAA2
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      VZ2=VZ
      EPS=1.0E-4
      IF(JJ.EQ.2) GO TO 201
      IF(JJ.GT.2) GO TO 202
      X1=VZAS
      Y1=VZ2
      VZ=VZ2
      JJ=JJ+1
      IF(VZ.LT.0.0.OR.VZ.GT.ASPEED) GO TO 999
      GO TO 200
  201 X2=VZAS
      Y2=VZ2
      VZ=WICNEW(X1,Y1,X2,Y2)
      IF(IPRINT.EQ.2) WRITE(6,203) JJ,VZ
  203 FORMAT(1H ,1X,I1,2X,≠VZ2=≠,F10.5)
      JJ=JJ+1
      IF(VZ.LT.0.0.OR.VZ.GT.ASPEED) GO TO 999
      GO TO 200
  202 IF(ABS((VZAS-VZ2)/VZAS).LT.EPS) GO TO 300
      X1=X2
      Y1=Y2
      X2=VZAS
      Y2=VZ2
      VZ=WICNEW(X1,Y1,X2,Y2)
      IF(IPRINT.EQ.2) WRITE(6,204) JJ,VZ
  204 FORMAT(1H0,1X,I1,2X,≠VZ2=≠,F10.5)
      JJ=JJ+1
      IF(VZ.LT.0.0.OR.VZ.GT.ASPEED) GO TO 999
      IF(JJ.EQ.20) GO TO 999
      GO TO 200
  300 VZ2CL=VZ
      IF(JJJ.EQ.2) GO TO 2010
      IF(JJJ.GT.2) GO TO 2020
      XX1=VZ2AS
      YY1=VZ2CL
      JJJ=JJJ+1
      GO TO 2000
 2010 XX2=VZ2AS
      YY2=VZ2CL
      VZ=WICNEW(XX1,YY1,XX2,YY2)
      IF(IPRINT.EQ.2) WRITE(6,2030) JJJ,VZ
 2030 FORMAT(1H ,1X,I2,≠VZ22=≠,F10.5)
      JJJ=JJJ+1
      GO TO 2000
 2020 IF(ABS((VZ2AS-VZ2CL)/VZ2AS).LT.EPS) GO TO 3000
      XX1=XX2
      YY1=YY2
      XX2=VZ2AS
      YY2=VZ2CL
      VZ=WICNEW(XX1,YY1,XX2,YY2)
      IF(IPRINT.EQ.2) WRITE(6,2040) JJJ,VZ
 2040 FORMAT(1H ,1X,I2,≠VZ22=≠,F10.5)
      JJJ=JJJ+1
      IF(JJJ.EQ.20) GO TO 3000
      GO TO 2000
 3000 VZ2=VZ2CL
      FAI2=VZ2/UTIPG(ISTAGE)
      P(2)=(1.0+G2*AMAC2**2)**G1*PS2
      JJJJ=1
 3001 VZ3AS=VZ
      CALL WICGSL(OMEGS(ISTAGE),SIGUMS(ISTAGE),BET1SS(ISTAGE),BET2SS
     $(ISTAGE),AINCSS(ISTAGE),ADEVSS(ISTAGE),AMAC2,ALFA2,DEQS,DEQN,
     $SITACS,SITACN,BET2N,OMEGAN,FMA2(ISTAGE),IDESIN,AK1,AK2,AK3,VZ2,
     $VZ3AS,0.0,RADI2(ISTAGE),RADI1(ISTAGE+1))
      OMEGA8=OMEGAN
      ALFA3=BET2N
      ALFA1R=ALFA2*PAI/180.0
      ALFA2R=ALFA3*PAI/180.0
      ALFAAV=(ALFA1R+ALFA2R)/2.0
      TANGT=WICTAN(ALFA1R)-WICTAN(ALFA2R)
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      CSAV=COS(ALFAAV)                                                  WICSPC
      CS1=COS(ALFA1R)                                                   WICSPC
      CL=2.0/SIGUMS(ISTAGE)*TANGT*CSAV                                  WICSPC
      CDS=0.018*(CL**2)                                                 WICSPC
      OMEGSE=CDS*SIGUMS(ISTAGE)*(CS1**2)/(CSAV**3)                      WICSPC
      H=SRTIP(ISTAGE)-SRHUB(ISTAGE)                                     WICSPC
      SHR=SC(ISTAGE)/H/SIGUMR(ISTAGE)                                   WICSPC
      CDA=0.020*SHR                                                     WICSPC
      OMEGAN=CDA*SIGUMS(ISTAGE)*(CS1**2)/(CSAV**3)                      WICSPC
      IF(IPRINT.EQ.2) WRITE(6,3002)                                     WICSPC
     $OMEGA4,OMEGSE,OMEGAN,OMEGA8,CDS,CDA                               WICSPC
 3002 FORMAT(1H0,6F10.5)                                                WICSPC
      OMES2=OMEGSE                                                      WICSPC
      OMEA2=OMEGAN                                                      WICSPC
      AINCIS=ALFA2-BET1MS(ISTAGE)                                       WICSP(
      ADEVIS=BET2N-BET2MS(ISTAGE)                                       WICSPC
      ALFA3R=ALFA3*PAI/180.0                                            WICSPC
      V3=V2/COS(ALFA3R)                                                 WICSPC
      CALL WICRSL(SIGUMS(ISTAGE),ALFA2,ALFA3,SC(ISTAGE),DAV,CDR,OMEGAR) WICSPC
      DELP4=OMEGA4*0.5*RHOG(2)/GC*(V2**2)                               WICSPC
      IF(IPRINT.EQ.2) WRITE(6,3003) OMEGA4,DELP4                        WICSPC
 3003 FORMAT(1H ,1X,≠OMEGA4=≠,2F10.5)                                   WICSPC
      CALL WICISL(ISTALE,SRTIP(ISTAGE),XWW(2),XG,RHOG(2),ALFA2,V2,WW1   WICSPC
     $,WW2,WW)                                                          WICSPC
      BMIMPS=WW                                                         WICSPC
      IF(BMIMPS.GT.WWMAS) BMIMPS=WWMAS                                  WICSPC
      BMREBS=BMIMPS*PREB/100.0                                          WICSPC
      BMWAKS=BMIMPS*(1.0-PREB/100.0)                                    WICSPC
      IF(IPRINT.EQ.2) WRITE(6,6616)                                     WICSPC
 6616 FORMAT(1H ,1X,≠IMPINS≠)                                           WICSPC
      IF(IPRINT.EQ.2) WRITE(6,6617) XWW(2),XA,RHOG(2),VZ,WW,BMIMPS,BM   WICSPC
     $REBS,BMWAKS                                                       WICSPC
 6617 FORMAT(1H ,8(F12.5,1X))                                           WICSPC
      RST1=RADI2(ISTAGE)**2-AAA2*144.0/2.0/PAI                          WICSPC
      RST1=SQRT(RST1)                                                   WICSPC
      RST2=2.0*RADI2(ISTAGE)**2-RST1**2                                 WICSPC
      RST2=SQRT(RST2)                                                   WICSPC
      DELR=(RST2-RST1)/12.0                                             WICSPC
      FMASSS=BMWAKS/DELR                                                WICSPC
      CALL WICFML(V2,V3,FMASSS,RHOG2,SC(ISTAGE),SIGUMS(ISTAGE),BETA1,   WICSPC
     $BETA2,CDF,OMEGAF)                                                 WICSPC
      OMEGA5=OMEGAF                                                     WICSPC
      DELP5=OMEGA5*0.5*RHOG(2)/GC*(V2**2)                               WICSPC
      IF(IPRINT.EQ.2) WRITE(6,6618) OMEGA5,DELP5                        WICSPC
 6618 FORMAT(1H ,1X,≠OMEGA5=≠,2F10.5)                                   WICSPC
      CALL WICSTL(ISTAGE,2,DAV,W1,W2,DELV,V2,V3,WWMAS,VZ,N,BETA1,BETA2, WICSPC
     $ALFA2,ALFA3,BMASS,DELVU2,DELVL2,OMEGRU,OMEGRL,OMEGSU,OMEGSL,      WICSPC
     $DRAGRU,DRAGRL,DRAGSU,DRAGSL,REAVE)                                WICSPC
      OMEGA6=OMEGSU+OMEGSL                                              WICSPC
      DELP6=OMEGA6*0.5*RHOG(2)/GC*(V2**2)                               WICSPC
      IF(IPRINT.EQ.2) WRITE(6,6619) OMEGA6,DELP6                        WICSPC
 6619 FORMAT(1H ,1X,≠OMEGA6=≠,2F10.5)                                   WICSPC
      REAVE2=REAVE                                                      WICSPC
      REAVE=(REAVE1+REAVE2)*0.5                                         WICSPC
      PR23=1.0-(OMEGA8+OMEGA4+OMEGA5+OMEGA6)*(1.0-PS2/P(2))             WICSPC
      PR13=(TG(2)/TG(1))**G1*PRREL*PR23/PP                              WICSPC
      PR13I=(TG(2)/TG(1))**G1                                           WICSPC
      P(3)=PR13*P(1)                                                    WICSPC
      TG(3)=TG(2)                                                       WICSPC
      TS3=TG(3)-V3**2/(2.0*CPMIX*GC*AJ)                                 WICSPC
      AG3=(GAMMA*RMIX*TS3*GC)**0.5                                      WICSPC
      ASPEED=WICASD(XWT(1),RHOG(2),AG3)                                 WICSPC
      ASPED3=ASPEED                                                     WICSPC
      AMAC3=V3/ASPEED                                                   WICSPC
      PS3=(1.0+G2*AMAC3**2)**(-G1)*P(3)                                 WICSPC
      RHOG3=PS3/RMIX/TS3                                                WICSPC
      RHOG(3)=RHOG3                                                     WICSPC
      RHOM3=1.0/(XG/RHOG3+XWT(1)/RHOW)                                  WICSPC
      VZ=BMASS/RHOG3/AAA3                                               WICSPC
      VZ3CL=VZ                                                          WICSPC
```

```
      IF(JJJJ.EQ.2) GO TO 3010
      IF(JJJJ.GT.2) GO TO 3020
      XXX1=VZ3AS
      YYY1=VZ3CL
      JJJJ=JJJJ+1
      GO TO 3001
 3010 XXX2=VZ3AS
      YYY2=VZ3CL
      VZ=WICNEW(XXX1,YYY1,XXX2,YYY2)
      IF(IPRINT.EQ.2) WRITE(6,3030) JJJJ,VZ
 3030 FORMAT(1H ,1X,I2,2X,≠VZ33=≠,F10.5)
      JJJJ=JJJJ+1
      GO TO 3001
 3020 IF(ABS((VZ3AS-VZ3CL)/VZ3AS).LT.EPS) GO TO 4000
      XXX1=XXX2
      YYY1=YYY2
      XXX2=VZ3AS
      YYY2=VZ3CL
      VZ=WICNEW(XXX1,YYY1,XXX2,YYY2)
      IF(IPRINT.EQ.2) WRITE(6,3040) JJJJ,VZ
 3040 FORMAT(1H ,1X,I2,≠VZ33=≠,F10.5)
      JJJJ=JJJJ+1
      IF(JJJJ.EQ.20) GO TO 4000
      GO TO 3001
 4000 VZ3=VZ3CL
      FAI3=VZ3/UTIPG(ISTAGE+1)
      TW(3)=TW(2)
      TWW(3)=TW(2)
      OMEGTR=OMEGA1+OMEGA2+OMEGA3+OMEGA7
      OMEGTS=OMEGA4+OMEGA5+OMEGA6+OMEGA8
      POMEG1=OMEGA1/OMEGTR*100.0
      POMEG2=OMEGA2/OMEGTR*100.0
      POMEG3=OMEGA3/OMEGTR*100.0
      POMEG4=OMEGA4/OMEGTS*100.0
      POMEG5=OMEGA5/OMEGTS*100.0
      POMEG6=OMEGA6/OMEGTS*100.0
      POMEG7=OMEGA7/OMEGTR*100.0
      POMEG8=OMEGA8/OMEGTS*100.0
      PRATIO=P(3)/P(1)
      TRATIO=TG(3)/TG(1)
      CALL WICPRP(XA,XV(3),XCH4,TG(3),RMIX,CPMIX,GAMMA,G1,G2,G3)
      GAMMA2=GAMMA
      GAMMAV=(GAMMA1+GAMMA2)/2.0
      G4=(GAMMAV-1.0)/GAMMAV
      ETAA(ISTAGE)=(PRATIO**G4-1.0)/(TRATIO-1.0)
      IF(IUNIT.NE.2) GO TO 859
      UTIPG(ISTAGE)=UTIPG(ISTAGE)*CFV
      P(1)=P(1)*CFP
      P(2)=P(2)*CFP
      P(3)=P(3)*CFP
      PS1=PS1*CFP
      PS2=PS2*CFP
      PS3=PS3*CFP
      TG(1)=TG(1)*CFT
      TG(2)=TG(2)*CFT
      TG(3)=TG(3)*CFT
      TS1=TS1*CFT
      TS2=TS2*CFT
      TS3=TS3*CFT
      RHOG(1)=RHOG(1)*CFD
      RHOG2=RHOG2*CFD
      RHOG3=RHOG3*CFD
      RHOM(1)=RHOM(1)*CFD
      RHOM2=RHOM2*CFD
      RHOM3=RHOM3*CFD
      VZ1=VZ1*CFV
      VZ2=VZ2*CFV
      VZ3=VZ3*CFV
      V1=V1*CFV
      V2=V2*CFV
```

```
      V3=V3*CFV                                                          WICSPC
      W1=W1*CFV                                                          WICSPC
      W2=W2*CFV                                                          WICSPC
      U(ISTAGE)=U(ISTAGE)*CFV                                            WICSPC
      UU2(ISTAGE)=UU2(ISTAGE)*CFV                                        WICSPC
      U(ISTAGE+1)=U(ISTAGE+1)*CFV                                        WICSPC
      VS1=VS1*CFV                                                        WICSPC
      VS2=VS2*CFV                                                        WICSPC
      WS1=WS1*CFV                                                        WICSPC
      WS2=WS2*CFV                                                        WICSPC
      ASPED1=ASPED1*CFV                                                  WICSPC
      ASPED2=ASPED2*CFV                                                  WICSPC
      ASPED3=ASPED3*CFV                                                  WICSPC
      AAA1=AAA1*CFA                                                      WICSPC
      AAA2=AAA2*CFA                                                      WICSPC
      AAA3=AAA3*CFA                                                      WICSPC
  859 CONTINUE                                                           WICSPC
      WRITE(6,404) FAIO,ISTAGE                                           WICSPC
  404 FORMAT(1H1,1X,≠********************  ≠,1X,                         WICSPC
     $≠INITIAL FLOW COEFFICIENT-≠,1X,F7.5,1X,≠(STAGE=≠,I2,1X,            WICSPC
     $≠)≠,2X,≠********************≠)                                     WICSPC
       WRITE(6,401) PRATIO,TRATIO,ETAA(ISTAGE)                           WICSPC
  401 FORMAT(1H0,5X,≠STAGE TOTAL PRESSURE RATIO=≠,F12.5,/,               WICSPC
     $6X,≠STAGE TOTAL TEMPERATURE RATIO=≠,F12.5,/,                       WICSPC
     $6X,≠STAGE ADIABATIC EFFICIENCY=≠,F12.5)                            WICSPC
       WRITE(6,402) FAI1,VZ1,UTIPG(ISTAGE)                               WICSPC
  402 FORMAT(1H0,5X,≠STAGE FLOW COEFFICIENT=≠,F5.3,/,                    WICSPC
     $6X,≠AXIAL VELOCITY=≠,F7.2,/,                                       WICSPC
     $6X,≠ROTOR SPEED=≠,F7.2,/)                                          WICSPC
      WRITE(6,403) PR13,PR13I,PRREL,PR23                                 WICSPC
  403 FORMAT(1H ,5X,≠STAGE TOTAL PRESSURE RATIO(ACTUAL)=≠,F12.5,/,       WICSPC
     $6X,≠STAGE TOTAL PRESSURE RATIO(IDEAL)=≠,F12.5,/,                   WICSPC
     $6X,≠LOSS FACTOR IN ROTOR=≠,F12.5,/,                                WICSPC
     $6X,≠LOSS FACTOR IN STATOR=≠,F12.5,/)                               WICSPC
      WRITE(6,405)                                                       WICSPC
  405 FORMAT(1H0,24X,≠*ROTOR INLET* *ROTOR OUTLET* *STATOR OUTLET*≠)     WICSPC
      WRITE(6,406) P(1),P(2),P(3)                                        WICSPC
  406 FORMAT(1H ,1X,≠TOTAL PRESSURE≠,10X,3(F10.2,5X))                    WICSPC
      WRITE(6,407) PS1,PS2,PS3                                           WICSPC
  407 FORMAT(1H ,1X,≠STATIC PRESSURE≠,9X,3(F10.2,5X))                    WICSPC
      WRITE(6,408) TG(1),TG(2),TG(3)                                     WICSPC
  408 FORMAT(1H ,1X,≠TOTAL TEMPERATURE(GAS)≠,3X,3(F10.4,5X))             WICSPC
      WRITE(6,409) TS1,TS2,TS3                                           WICSPC
  409 FORMAT(1H ,1X,≠STATIC TEMPERATURE(GAS)≠,1X,3(F10.4,5X))            WICSPC
      WRITE(6,410) RHOG(1),RHOG2,RHOG3                                   WICSPC
  410 FORMAT(1H ,1X,≠STATIC DENSITY(GAS)≠,5X,3(F10.4,5X))                WICSPC
      WRITE(6,411) RHOM(1),RHOM2,RHOM3                                   WICSPC
  411 FORMAT(1H ,1X,≠STATIC DENSITY(MIXTURE)≠,1X,3(F10.4,5X))            WICSPC
      WRITE(6,412) VZ1,VZ2,VZ3                                           WICSPC
  412 FORMAT(1H0,1X,≠AXIAL VELOCITY≠,10X,3(F10.4,5X))                    WICSPC
      WRITE(6,413) V1,V2,V3                                              WICSPC
  413 FORMAT(1H ,1X,≠ABSOLUTE VELOCITY≠,7X,3(F10.4,5X))                  WICSPC
      WRITE(6,414) W1,W2                                                 WICSPC
  414 FORMAT(1H ,1X,≠RELATIVE VELOCITY≠,7X,2(F10.4,5X))                  WICSPC
      WRITE(6,415) U(ISTAGE),UU2(ISTAGE),U(ISTAGE+1)                     WICSPC
  415 FORMAT(1H ,1X,≠BLADE SPEED≠,13X,3(F10.4,5X))                       WICSPC
      WRITE(6,416) VS1,VS2                                               WICSPC
  416 FORMAT(1H ,1X,≠TANG. COMP. OF ABS. VEL.≠,2(F10.4,5X))              WICSPC
      WRITE(6,417) WS1,WS2                                               WICSPC
  417 FORMAT(1H ,1X,≠TANG. COMP. OF REL. VEL.≠,2(F10.4,5X))              WICSPC
      WRITE(6,418) ASPED1,ASPED2,ASPED3                                  WICSPC
  418 FORMAT(1H ,1X,≠ACOUSTIC SPEED≠,10X,3(F10.4,5X))                    WICSPC
      WRITE(6,419) AMAC1,AMAC2,AMAC3                                     WICSPC
  419 FORMAT(1H ,1X,≠ABSOLUTE MACH NUMBER≠,4X,3(F10.4,5X))               WICSPC
      WRITE(6,420) AMACH1,AMACH2                                         WICSPC
  420 FORMAT(1H ,1X,≠RELATIVE MACH NUMBER≠,4X,2(F10.4,5X))               WICSPC
      WRITE(6,421) FAI1,FAI2,FAI3                                        WICSPC
  421 FORMAT(1H0,1X,≠FLOW COEFFICIENT≠,8X,3(F10.4,5X))                   WICSPC
      WRITE(6,422) AAA1,AAA2,AAA3                                        WICSPC
  422 FORMAT(1H ,1X,≠FLOW AREA≠,15X,3(F10.4,5X))                         WICSPC
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      WRITE(6,423) ALFA1,ALFA2,ALFA3                                    WICSPC
  423 FORMAT(1H0,1X,≠ABSOLUTE FLOW ANGLE≠,5X,3(F10.4,5X))               WICSPC
      WRITE(6,424) BETA1,BETA2                                          WICSPC
  424 FORMAT(1H ,1X,≠RELATIVE FLOW ANGLE≠,5X,3(F10.4,5X))               WICSPC
      WRITE(6,425) AINCIR,AINCIS                                        WICSPC
  425 FORMAT(1H ,1X,≠INCIDENCE≠,16X,2(F10.4,5X))                        WICSPC
      WRITE(6,426) ADEVIR,ADEVIS                                        WICSPC
  426 FORMAT(1H ,1X,≠DEVIATION≠,30X,2(F10.4,5X))                        WICSPC
      IF(IUNIT.NE.2) GO TO 860                                          WICSPC
      UTIPG(ISTAGE)=UTIPG(ISTAGE)/CFU                                   WICSPC
      P(1)=P(1)/CFP                                                     WICSPC
      P(2)=P(2)/CFP                                                     WICSPC
      P(3)=P(3)/CFP                                                     WICSPC
      PS1=PS1/CFP                                                       WICSPC
      PS2=PS2/CFP                                                       WICSPC
      PS3=PS3/CFP                                                       WICSPC
      TG(1)=TG(1)/CFT                                                   WICSPC
      TG(2)=TG(2)/CFT                                                   WICSPC
      TG(3)=TG(3)/CFT                                                   WICSPC
      TS1=TS1/CFT                                                       WICSPC
      TS2=TS2/CFT                                                       WICSPC
      TS3=TS3/CFT                                                       WICSPC
      RHOG(1)=RHOG(1)/CFD                                               WICSPC
      RHOG2=RHOG2/CFD                                                   WICSPC
      RHOG3=RHOG3/CFD                                                   WICSPC
      RHOM(1)=RHOM(1)/CFD                                               WICSPC
      RHOM2=RHOM2/CFD                                                   WICSPC
      RHOM3=RHOM3/CFD                                                   WICSPC
      VZ1=VZ1/CFV                                                       WICSPC
      VZ2=VZ2/CFV                                                       WICSPC
      VZ3=VZ3/CFV                                                       WICSPC
      V1=V1/CFV                                                         WICSPC
      V2=V2/CFV                                                         WICSPC
      V3=V3/CFV                                                         WICSPC
      W1=W1/CFV                                                         WICSPC
      W2=W2/CFV                                                         WICSPC
      U(ISTAGE)=U(ISTAGE)/CFV                                           WICSPC
      UU2(ISTAGE)=UU2(ISTAGE)/CFV                                       WICSPC
      U(ISTAGE+1)=U(ISTAGE+1)/CFV                                       WICSPC
      VS1=VS1/CFV                                                       WICSPC
      VS2=VS2/CFV                                                       WICSPC
      WS1=WS1/CFV                                                       WICSPC
      WS2=WS2/CFV                                                       WICSPC
      ASPED1=ASPED1/CFV                                                 WICSPC
      ASPED2=ASPED2/CFV                                                 WICSPC
      ASPED3=ASPED3/CFV                                                 WICSPC
      AAA1=AAA1/CFA                                                     WICSPC
      AAA2=AAA2/CFA                                                     WICSPC
      AAA3=AAA3/CFA                                                     WICSPC
  860 CONTINUE                                                          WICSPC
  999 RETURN                                                            WICSPC
      END                                                               WICSPC
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ WICMAC
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICMAC
C                                                                     C WICMAC
C SUBROUTINE WICMAC                                                   C WICMAC
C                                                                     C WICMAC
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICMAC
      SUBROUTINE WICMAC(ISTAGE,AMASSM,T01G,PRES,M,VZ,C,XW1,ALFA,        WICMAC
     $RMIX,CPMIX,AREA1)                                                 WICMAC
      REAL M ,MA1,MC1,MA2,MC2,MANEW,MCNEW                               WICMAC
      COMMON TD(7),IUNIT                                                WICMAC
      COMMON CFL,CFT,CFP,CFD,CFM,CFV,CFA                                WICMAC
      COMMON JPERFM,RHOG(3),RERUP,RERLOW,RESUP,RESLOW                   WICMAC
      COMMON PRED,RRTIP(8),SRTIP(8),AAA1,AAA2,AAA3,SAREA(6),SAREAS(7)   WICMAC
      COMMON P(3),TG(3),XA,XV(3),XCH4,XW(3),XWW(3),XWT(3),TW(3),TWW(3)  WICMAC
      COMMON OMEGS(7),OMEGR(6),GAPR(6),GAPS(6)                          WICMAC
      COMMON RRHUB(6) , RC(6) , RBLADE(6) , STAGER(6)                   WICMAC
      COMMON SRHUB(7) , SC(7) , SBLADE(7) , STAGES(7)                   WICMAC
      COMMON SIGUMR(6) , BET1SR(6) , BET2SR(6) , AINCSR(6) , ADEVSR(6)  WICMAC
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      COMMON SIGUMS(7) , BET1SS(7) , BET2SS(7) , AINCSS(7) , ADEVSS(7)    WICMAC
      COMMON UTIPG(6),UTIP(6),UTIPD(6),UOU(6),UMEAN(6),UHUB(6),U(6),FAI   WICMAC
      COMMON AREA(6),AREAS(7),UU2(6),UTIP2(6),UMEAN2(6),UHUB2(6),IPRINT   WICMAC
      COMMON ICENT,IICENT,FMR1(6),FMA2(6),IDESIN,FAID                     WICMAC
      COMMON NS,NS1,RT(6),RM(6),RH(6),ST(6),SM(6),SH(6)                   WICMAC
      COMMON DSMASS,AAREA(7),AAREAS(7),PR12D(6),PR13D(6),ETARD(6)         WICMAC
      COMMON DR(6),DS(6),DEQR(6),DEQS(6),BLOCK(6),BLOCKS(7)               WICMAC
      COMMON BET1MR(6),BET2MR(6),BET1MS(7),BET2MS(7),RADI1(6),RADI2(6)    WICMAC
      GAMMA=1.0/(1.0-RMIX/CPMIX/778.0)                                    WICMAC
      G2=(GAMMA-1.0)/2.0                                                  WICMAC
      G3=-1.0/(GAMMA-1.0)                                                 WICMAC
      MA1=0.5                                                             WICMAC
      RHOG1=PRES/RMIX/T01G                                                WICMAC
      RHOGS=(1.0+G2*MA1**2)**G3*RHOG1                                     WICMAC
      RHOW=62.4                                                           WICMAC
      RHOMS=1.0/((1.0-XW1)/RHOGS+XW1/RHOW)                                WICMAC
      TS=T01G/(1.0+G2*MA1**2)                                             WICMAC
      A=SQRT(GAMMA*RMIX*TS*32.174)                                        WICMAC
      C=WICASD(XW1,RHOGS,A)                                               WICMAC
      IF(JPERFM.NE.3) VZ=AMASSM/RHOMS/AREA1                               WICMAC
      IF(JPERFM.EQ.3) VZ=AMASSM/RHOGS/AREA1                               WICMAC
      IF(AMASSM.LT.0.001) VZ=UTIPG(ISTAGE)*FAI                            WICMAC
      ALFAR=ALFA*3.1415927/180.0                                          WICMAC
      MC1=VZ/C/COS(ALFAR)                                                 WICMAC
      MA2=0.6                                                             WICMAC
      RHOGS=(1.0+G2*MA2**2)**G3*RHOG1                                     WICMAC
      RHOMS=1.0/((1.0-XW1)/RHOGS+XW1/RHOW)                                WICMAC
      TS=T01G/(1.0+G2*MA2**2)                                             WICMAC
      A=SQRT(GAMMA*RMIX*TS*32.174)                                        WICMAC
      C=WICASD(XW1,RHOGS,A)                                               WICMAC
      IF(JPERFM.NE.3) VZ=AMASSM/RHOMS/AREA1                               WICMAC
      IF(JPERFM.EQ.3) VZ=AMASSM/RHOGS/AREA1                               WICMAC
      IF(AMASSM.LT.0.001) VZ=UTIPG(ISTAGE)*FAI                            WICMAC
      MC2=VZ/C/COS(ALFAR)                                                 WICMAC
      J=1                                                                 WICMAC
  300 MANEW=WICNEW(MA1,MC1,MA2,MC2)                                       WICMAC
      RHOGS=(1.0+G2*MANEW**2)**G3*RHOG1                                   WICMAC
      RHOMS=1.0/((1.0-XW1)/RHOGS+XW1/RHOW)                                WICMAC
      TS=T01G/(1.0+G2*MANEW**2)                                           WICMAC
      A=SQRT(GAMMA*RMIX*TS*32.174)                                        WICMAC
      C=WICASD(XW1,RHOGS,A)                                               WICMAC
      IF(JPERFM.NE.3) VZ=AMASSM/RHOMS/AREA1                               WICMAC
      IF(JPERFM.EQ.3) VZ=AMASSM/RHOGS/AREA1                               WICMAC
      IF(AMASSM.LT.0.001) VZ=UTIPG(ISTAGE)*FAI                            WICMAC
      MCNEW=VZ/C/COS(ALFAR)                                               WICMAC
      ERROR=ABS(MANEW-MCNEW)                                              WICMAC
      ERROR=ERROR/MANEW                                                   WICMAC
      EPS=1.0E-6                                                          WICMAC
      IF(ERROR.LT.EPS) GO TO 200                                          WICMAC
      MA1=MA2                                                             WICMAC
      MC1=MC2                                                             WICMAC
      MA2=MANEW                                                           WICMAC
      MC2=MCNEW                                                           WICMAC
      J=J+1                                                               WICMAC
      IF(J.LT.50) GO TO 300                                               WICMAC
      WRITE(6,403) ISTAGE                                                 WICMAC
  403 FORMAT(1H0,≠MZ DOES NOT CONVERGE AT STAGE=≠,I1)                     WICMAC
      GO TO 998                                                           WICMAC
  200 M=MANEW                                                             WICMAC
      IF(AMASSM.LT.0.001) ISTAGE=0                                        WICMAC
  998 RETURN                                                              WICMAC
      END                                                                 WICMAC
C++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ WICASD
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICASD
C                                                                       C WICASD
C FUNCTION WICASD                                                      C  WICASD
C                                                                       C WICASD
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICASD
      FUNCTION WICASD ( XW , RHOG , CG )                                  WICASD
      RHOW=62.2567                                                        WICASD
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      CW = 4956.04
      SIGUMA = ( XW * RHOG ) / ( RHOW - XW * ( RHOW - RHOG ))
      A1 = ( 1.0-SIGUMA ) * RHOG + SIGUMA * RHOW
      A2 = ( 1.0- SIGUMA ) / ( RHOG * CG* CG )
      A3 = SIGUMA / ( RHOW * CW* CW)
      A4 = A1 * ( A2 + A3)
      WICASD = 1.0/ SQRT ( A4 )
      RETURN
      END
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                     C
C SUBROUTINE WICBOA                                                   C
C                                                                     C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE WICBOA(OMEGAS,SIGUMA,BET1S,BET2S,AINCIS,ADEVIS,AMACH1,
     1BET1,DEQS,DEQN,SITACS,SITACN,BET2N,X,AK1,AK3,VZ1,VZ2,UR1,R1,R2)
      CALL WICEDD(AK3,VZ1,VZ2,UR1,R1,R2,BET1S,BET2S,SIGUMA,OMEGAS,
     $DEQS,SITACS)
      AINCI=BET1+AINCIS-BET1S
      BET2A=BET2S
      X1=BET2A
      DELDEQ=WICED(AK3,VZ1,VZ2,UR1,R1,R2,BET1,X1,SIGUMA,AINCIS,AINCI)
     $-DEQS
      ADEVI=ADEVIS+(6.40-9.45*AMACH1+9.45*X)*DELDEQ*AK1
      IF(AMACH1.LT.X) ADEVI=ADEVIS+6.40*DELDEQ*AK1
      BET2C=BET2S-ADEVIS+ADEVI
      Y1=BET2C
      N=1
   12 IF(N.GT.1) GO TO 10
      BET2A=BET2S*1.1
   10 X2=BET2A
      DEQN=WICED(AK3,VZ1,VZ2,UR1,R1,R2,BET1,X2,SIGUMA,AINCIS,AINCI)
      DELDEO=DEQN-DEQS
      ADEVI=ADEVIS+(6.40-9.45*AMACH1+9.45*X)*DELDEQ*AK1
      IF(AMACH1.LT.X) ADEVI=ADEVIS+6.40*DELDEQ*AK1
      BET2C=BET2S-ADEVIS+ADEVI
      Y2=BET2C
      DELBET=ABS((X2-Y2)/X2)
      EPS=1.0E-6
      IF(DELBET.LE.EPS) GO TO 11
      BET2A=WICNEW(X1,Y1,X2,Y2)
      X1=X2
      Y1=Y2
      N=N+1
      IF(N.GT.50) GO TO 13
      GO TO 12
   11 BET2N=X2
      GO TO 15
   13 WRITE(6,201)
  201 FORMAT(1H0,≠DO NOT CONVERGE≠)
   15 RETURN
      END
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                     C
C SUBROUTINE WICEDD                                                   C
C                                                                     C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE WICEDD(AK3,VZ1,VZ2,UR1,R1,R2,BET1S,BET2S,SIGUMA,
     $OMEGAS,DEQS,SITACS)
      C1=180.0/3.1415926
      BET1SR=BET1S/C1
      BET2SR=BET2S/C1
      CSB1=COS(BET1SR)
      CSB2=COS(BET2SR)
      CSCS=CSB2/CSB1*(VZ1/VZ2)
      CSCSS=CSB2/CSB1
      TNB1=WICTAN(BET1SR)
      TNB2=WICTAN(BET2SR)*(VZ2/VZ1)*(R2/R1)
```

```
      TNTN=TNB1-TNB2-(UR1/VZ1)*(1.0-(R2/R1)**2)                           WICEDD
      DEQS=1.12*CSCS+0.61*(CSB1**2)/SIGUMA*TNTN*CSCS                      WICEDD
      DEOS=AK3*DEQS                                                       WICEDD
      SITACS=OMEGAS*CSB2/2.0/SIGUMA*(CSCSS**2)                            WICEDD
      RETURN                                                              WICEDD
      END                                                                 WICEDD
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++   WICED
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICED
C                                                                     C  WICED
C FUNCTION WICED                                                      C  WICED
C                                                                     C  WICED
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICED
      FUNCTION WICED(AK3,VZ1,VZ2,UR1,R1,R2,BET1,BET2,SIGUMA,AINCIS,       WICED
     $AINCI)                                                              WICED
      C1=180.0/3.1415926                                                  WICED
      BET1R=BET1/C1                                                       WICED
      BET2R=BET2/C1                                                       WICED
      CSB1=COS(BET1R)                                                     WICED
      CSB2=COS(BET2R)                                                     WICED
      CSCS=CSB2/CSB1*(VZ1/VZ2)                                            WICED
      TNB1=WICTAN(BET1R)                                                  WICED
      TNB2=WICTAN(BET2R)*(VZ2/VZ1)*(R2/R1)                                WICED
      TNTN=TNB1-TNB2-(UR1/VZ1)*(1.0-(R2/R1)**2)                           WICED
      DEQ1=1.12*CSCS                                                      WICED
      AAA=ABS(AINCI-AINCIS)                                               WICED
      DEQ2=0.0117*(AAA**1.43)*CSCS                                        WICED
      DEQ3=0.61*(CSB1**2)/SIGUMA*TNTN*CSCS                                WICED
      WICED=DEQ1+DEQ2+DEQ3                                                WICED
      WICED=AK3*WICED                                                     WICED
      RETURN                                                              WICED
      END                                                                 WICED
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++   WICMTK
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICMTK
C                                                                     C  WICMTK
C FUNCTION WICMTK                                                     C  WICMTK
C                                                                     C  WICMTK
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICMTK
      FUNCTION WICMTK(SITACS,AMACH1,DELDEQ,AK2)                           WICMTK
      IF(DELDEQ.LT.0.0) GO TO 10                                          WICMTK
      A1=0.827*AMACH1                                                     WICMTK
      A2=2.692*(AMACH1**2)                                                WICMTK
      A3=2.675*(AMACH1**3)                                                WICMTK
      A=A1-A2+A3                                                          WICMTK
      WICMTK=SITACS+A*(DELDEQ**2)*AK2                                     WICMTK
      GO TO 11                                                            WICMTK
   10 B1=2.80*AMACH1                                                      WICMTK
      B2=8.71*(AMACH1**2)                                                 WICMTK
      B3=9.36*(AMACH1**3)                                                 WICMTK
      B=B1-B2+B3                                                          WICMTK
      WICMTK=SITACS+B*(DELDEQ**2)*AK2                                     WICMTK
   11 RETURN                                                              WICMTK
      END                                                                 WICMTK
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++  WICLOS
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICLOS
C                                                                     C  WICLOS
C FUNCTION WICLOS                                                     C  WICLOS
C                                                                     C  WICLOS
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICLOS
      FUNCTION WICLOS(BET1,BET2,SIGUMA,SITA)                              WICLOS
      C1=180.0/3.1415926                                                  WICLOS
      BET1R=BET1/C1                                                       WICLOS
      BET2R=BET2/C1                                                       WICLOS
      CSB1=COS(BET1R)                                                     WICLOS
      CSB2=COS(BET2R)                                                     WICLOS
      CSCS=CSB1/CSB2                                                      WICLOS
      WICLOS=SITA*2.0*SIGUMA/CSB2*(CSCS**2)                               WICLOS
      RETURN                                                              WICLOS
      END                                                                 WICLOS
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++  WICIRS
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICIRS
```

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C                                                                     C  WICIRS
C SUBROUTINE WICIRS                                                   C  WICIRS
C                                                                     C  WICIRS
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICIRS
      SUBROUTINE WICIRS(ISTAGE,R,XW1,XG,RHOG1,BETA1,W1,                   WICIRS
     1WW1 , WW2 , WW )                                                    WICIRS
      REAL LWC                                                            WICIRS
      COMMON TD(7),IUNIT                                                  WICIRS
      COMMON CFL,CFT,CFP,CFD,CFM,CFV,CFA                                  WICIRS
      COMMON JPERFM,RHOG(3),RERUP,RERLOW,RESUP,RESLOW                     WICIRS
      COMMON PREB,RRTIP(8),SRTIP(8),AAA1,AAA2,AAA3,SAREA(6),SAREAS(7)     WICIRS
      COMMON P(3),TG(3),XA,XV(3),XCH4,XW(3),XWW(3),XWT(3),TW(3),TWW(3)    WICIRS
      COMMON OMEGS(7),OMEGR(6),GAPR(6),GAPS(6)                            WICIRS
      COMMON RRHUB(6) , RC(6) , RBLADE(6) , STAGER(6)                     WICIRS
      COMMON SRHUB(7) , SC(7) , SBLADE(7) , STAGES(7)                     WICIRS
      COMMON SIGUMR(6) , BET1SR(6) , BET2SR(6) , AINCSR(6) , ADEVSR(6)    WICIRS
      COMMON SIGUMS(7) , BET1SS(7) , BET2SS(7) , AINCSS(7) , ADEVSS(7)    WICIRS
      COMMON UTIPG(6),UTIP(6),UTIPD(6),UOV(6),UMEAN(6),UHUB(6),U(6),FAI   WICIRS
      COMMON AREA(6),AREAS(7),UU2(6),UTIP2(6),UMEAN2(6),UHUB2(6),IPRINT   WICIRS
      COMMON ICENT,IICENT,FMR1(6),FMA2(6),IDESIN,FAID                     WICIRS
      COMMON NS,NS1,RT(6),RM(6),RH(6),ST(6),SM(6),SH(6)                   WICIRS
      COMMON DSMASS,AAREA(7),AAREAS(7),PR12D(6),PR13D(6),ETARD(6)         WICIRS
      COMMON DR(6),DS(6),DEQR(6),DEQS(6),BLOCK(6),BLOCKS(7)               WICIRS
      COMMON BET1MR(6),BET2MR(6),BET1MS(7),BET2MS(7),RADI1(6),RADI2(6)    WICIRS
      N = ISTAGE                                                          WICIRS
      PAI = 3.1415926                                                     WICIRS
      B1 = 1.0                                                            WICIRS
      B2R = ( 90.0 - BETA1 + STAGER ( N )) * PAI / 180.0                  WICIRS
      B2 = COS ( B2R )                                                    WICIRS
      LWC=XW1/XG*RHOG1                                                    WICIRS
      DS1=0.07*RC(N)                                                      WICIRS
      BETA1R = BETA1* PAI / 180.0                                         WICIRS
      DS2 = 2.0 * PAI * R / RBLADE(N) * COS (BETA1R) /                    WICIRS
     $COS(B2R)                                                            WICIRS
      IF(DS2.GE.RC(N)) DS2=RC(N)                                          WICIRS
      H=(AAA1*144.0)/(2.0*PAI*R)                                          WICIRS
      A1=DS1*H*RBLADE(N)/144.0                                            WICIRS
      A2=DS2*H*RBLADE(N)/144.0                                            WICIRS
      WW1 = LWC * W1 * B1 * A1                                            WICIRS
      WW2 = LWC * W1 * B2 * A2                                            WICIRS
      WW = WW1 + WW2                                                      WICIRS
      RETURN                                                              WICIRS
      END                                                                 WICIRS
C++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++  WICISS
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICISS
C                                                                     C  WICISS
C SUBROUTINE WICISS                                                   C  WICISS
C                                                                     C  WICISS
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICISS
      SUBROUTINE WICISS( ISTAGE ,R ,XW1, XG , RHOGAS ,ALFA2,V1 ,          WICISS
     $WW1,WW2,WW)                                                         WICISS
      REAL LWC                                                            WICISS
      COMMON TD(7),IUNIT                                                  WICISS
      COMMON CFL,CFT,CFP,CFD,CFM,CFV,CFA                                  WICISS
      COMMON JPERFM,RHOG(3),RERUP,RERLOW,RESUP,RESLOW                     WICISS
      COMMON PREB,RRTIP(8),SRTIP(8),AAA1,AAA2,AAA3,SAREA(6),SAREAS(7)     WICISS
      COMMON P(3),TG(3),XA,XV(3),XCH4,XW(3),XWW(3),XWT(3),TW(3),TWW(3)    WICISS
      COMMON OMEGS(7),OMEGR(6),GAPR(6),GAPS(6)                            WICISS
      COMMON RRHUB(6) , RC(6) , RBLADE(6) , STAGER(6)                     WICISS
      COMMON SRHUB(7) , SC(7) , SBLADE(7) , STAGES(7)                     WICISS
      COMMON SIGUMR(6) , BET1SR(6) , BET2SR(6) , AINCSR(6) , ADEVSR(6)    WICISS
      COMMON SIGUMS(7) , BET1SS(7) , BET2SS(7) , AINCSS(7) , ADEVSS(7)    WICISS
      COMMON UTIPG(6),UTIP(6),UTIPD(6),UOV(6),UMEAN(6),UHUB(6),U(6),FAI   WICISS
      COMMON AREA(6),AREAS(7),UU2(6),UTIP2(6),UMEAN2(6),UHUB2(6),IPRINT   WICISS
      COMMON ICENT,IICENT,FMR1(6),FMA2(6),IDESIN,FAID                     WICISS
      COMMON NS,NS1,RT(6),RM(6),RH(6),ST(6),SM(6),SH(6)                   WICISS
      COMMON DSMASS,AAREA(7),AAREAS(7),PR12D(6),PR13D(6),ETARD(6)         WICISS
      COMMON DR(6),DS(6),DEQR(6),DEQS(6),BLOCK(6),BLOCKS(7)               WICISS
      COMMON BET1MR(6),BET2MR(6),BET1MS(7),BET2MS(7),RADI1(6),RADI2(6)    WICISS
      LWC = XW1/ XG * RHOGAS                                              WICISS
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      DS1=( 0.06 * SC ( ISTAGE ) ) / 12.0                                 WICISS
      PAI=3.1415926                                                       WICISS
      B1=1.0                                                              WICISS
      B2R=(90.0-ALFA2+STAGES(ISTAGE))*PAI/180.0                           WICISS
      B2=COS(B2R)                                                         WICISS
      ALFA2R=ALFA2*PAI/180.0                                              WICISS
      DS2=2.0*PAI*R/SBLADE(ISTAGE)*COS(ALFA2R)/COS(B2R)                   WICISS
      IF(DS2.GT.SC(ISTAGE)) DS2=SC(ISTAGE)                                WICISS
      H=(AAA2*144.0)/(2.0*PAI*R)                                          WICISS
      A1=DS1*H*SBLADE(ISTAGE)/144.0                                       WICISS
      A2=DS2*H*SBLADE(ISTAGE)/144.0                                       WICISS
      WW1=LWC*V1*B1*A1                                                    WICISS
      WW2=LWC*V1*B2*A2                                                    WICISS
      WW=WW1+WW2                                                          WICISS
      RETURN                                                              WICISS
      END                                                                 WICISS
C++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ WICIRL
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICIRL
C                                                                       C WICIRL
C SUBROUTINE WICISL                                                     C WICIRL
C                                                                       C WICIRL
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICIRL
      SUBROUTINE WICISL(ISTAGE,R,XW1,XG,RHOG1,ALFA2,W1,WW1,WW2,WW)        WICIRL
      REAL LWC                                                            WICIRL
      COMMON TD(7),IUNIT                                                  WICIRL
      COMMON CFL,CFT,CFP,CFD,CFM,CFV,CFA                                  WICIRL
      COMMON JPERFM,RHOG(3),RERUP,RERLOW,RESUP,RESLOW                     WICIRL
      COMMON PREB,RRTIP(8),SRTIP(8),AAA1,AAA2,AAA3,SAREA(6),SAREAS(7)     WICIRL
      COMMON P(3),TG(3),XA,XV(3),XCH4,XW(3),XWW(3),XWT(3),TW(3),TWW(3)    WICIRL
      COMMON OMEGS(7),OMEGR(6),GAPR(6),GAPS(6)                            WICIRL
      COMMON RRHUB(6) , RC(6) , RBLADE(6) , STAGER(6)                     WICIRL
      COMMON SRHUB(7) , SC(7) , SBLADE(7) , STAGES(7)                     WICIRL
      COMMON SIGUMR(6) , BET1SR(6) , BET2SR(6) , AINCSR(6) , ADEVSR(6)    WICIRL
      COMMON SIGUMS(7) , BET1SS(7) , BET2SS(7) , AINCSS(7) , ADEVSS(7)    WICIRL
      COMMON UTIPG(6),UTIP(6),UTIPD(6),UOU(6),UMEAN(6),UHUB(6),U(6),FAI   WICIRL
      COMMON AREA(6),AREAS(7),UU2(6),UTIP2(6),UMEAN2(6),UHUB2(6),IPRINT   WICIRL
      COMMON ICENT,IICENT,FMR1(6),FMA2(6),IDESIN,FAID                     WICIRL
      COMMON NS,NS1,RT(6),RM(6),RH(6),ST(6),SM(6),SH(6)                   WICIRL
      COMMON DSMASS,AAREA(7),AAREAS(7),PR12D(6),PR13D(6),ETARD(6)         WICIRL
      COMMON DR(6),DS(6),DEQR(6),DEQS(6),BLOCK(6),BLOCKS(7)               WICIRL
      COMMON BET1MR(6),BET2MR(6),BET1MS(7),BET2MS(7),RADI1(6),RADI2(6)    WICIRL
      PAI=3.1415926                                                       WICIRL
      LWC = XW1/ XG * RHOG1                                               WICIRL
      ALFA=(90.0-ALFA2)/2.0*PAI/180.0                                     WICIRL
      BETA=(90.0+ALFA2)/2.0*PAI/180.0                                     WICIRL
      B1=SIN(ALFA)                                                        WICIRL
      B2=SIN(BETA)                                                        WICIRL
      V1=W1*COS(ALFA)                                                     WICIRL
      V2=W1*COS(BETA)                                                     WICIRL
      S=2.0*PAI*SRTIP(ISTAGE)/SBLADE(ISTAGE)/2.0                          WICIRL
      GSI=ALFA2+(90.0-ALFA2)/2.0                                          WICIRL
      GSIR=GSI*PAI/180.0                                                  WICIRL
      STAGR=STAGES(ISTAGE)*PAI/180.0                                      WICIRL
      Y2=GAPS(ISTAGE)/2.0*(WICTAN(STAGR)-WICTAN(GSIR))+S                  WICIRL
      DAMY1=(90.0-GSI)*PAI/180.0                                          WICIRL
      Y1=Y2*SIN(DAMY1)                                                    WICIRL
      DAMY2=(GSI-STAGES(ISTAGE))*PAI/180.0                                WICIRL
      DS1=Y1/SIN(DAMY2)                                                   WICIRL
      IF(DS1.GT.SC(ISTAGE)) DS1=SC(ISTAGE)                                WICIRL
      DAMY3=(90.-(90.0+ALFA2)/2.0)*PAI/180.0                              WICIRL
      DAMY4=STAGES(ISTAGE)*PAI/180.0                                      WICIRL
      DAMY5=ALFA2*PAI/180.0                                               WICIRL
      DAMY6=S-GAPS(ISTAGE)/2.0*(WICTAN(DAMY5)-WICTAN(DAMY3))              WICIRL
      DAMY7=COS(DAMY4)*WICTAN(DAMY3)+SIN(DAMY4)                           WICIRL
      DS2=DAMY6/DAMY7                                                     WICIRL
      IF(DS2.GT.SC(ISTAGE)) DS2=SC(ISTAGE)                                WICIRL
      H=(AAA2*144.0)/(2.0*PAI*R)                                          WICIRL
      A1=DS1*H*SBLADE(ISTAGE)/144.0                                       WICIRL
      A2=DS2*H*SBLADE(ISTAGE)/144.0                                       WICIRL
      WW1=LWC*V1*B1*A1                                                    WICIRL
```

```
      WW2=LWC*V2*B2*A2
      WW=WW1+WW2
      RETURN
      END
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                    C
C SUBROUTINE WICWAK                                                  C
C                                                                    C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE WICWAK ( RHOG , V , DWAKE , DWAKEM )
      VISCOF=1.20E-3
      SIGUMA = 4.6534E-3
      GC = 32.174
      WE=21.0
      DWAKE1 = ( WE * SIGUMA * GC ) / RHOG / V ** 2
      SN=VISCOF**2/(RHOG*SIGUMA*DWAKE1*GC)
      WELIMT=12.0*(1.0+SN**0.36)
      D1=WELIMT*SIGUMA*GC/(RHOG*V**2)
      WE=22.0
      DWAKE2=(WE*SIGUMA*GC)/RHOG/V**2
      SN=VISCOF**2/(RHOG*SIGUMA*DWAKE2*GC)
      WELIMT=12.0*(1.0+SN**0.36)
      D2=WELIMT*SIGUMA*GC/(RHOG*V**2)
      XXXX=WICNEW(DWAKE1,D1,DWAKE2,D2)
      SN=VISCOF**2/(RHOG*SIGUMA*XXXX*GC)
      WELIMT=12.0*(1.0+SN**0.36)
      DWAKE=WELIMT*SIGUMA*GC/(RHOG*V**2)
      DWAKEM = DWAKE / 3.2802 * 1.0E6
      RETURN
      END
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                    C
C SUBROUTINE WICHET                                                  C
C                                                                    C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE WICHET(TG1,TG3,TW1,TW3,DAVEN2,DAVEN,
     $DELZI,VZ,WMASS1,VMASS1,AMASS,CHMASS,CPG,CPW,DELTGH,DELTWH,RE)
      DIMENSION DELHET(51)
      REAL ND , KA , NV , MMASS,NU
      DELTGH=0.0
      DELTWH=0.0
      IF(WMASS1.LT.1.0E-6) GO TO 11
      PAI = 3.1415927
      DAVEAV=(DAVEN2+DAVEN)/2.0*1.0E-6*3.2802
      IF(DAVEAV.LT.1.0E-6) GO TO 11
      RHOW = 62.54
      ND = WMASS1    / ( RHOW * 4.0 / 3.0 * PAI * ( DAVEAV / 2.0 ) ** 3)
      KA = 0.015 / 3600.0
      PR=0.7
      NU=2.0+0.6*SQRT(RE)*PR**0.33
      HCONVE = KA / DAVEAV * NU
      J = 1
   10 DELT=((TG1-TW1)+(TG3-TW3))/2.0
      DELHH = HCONVE * 4.0 * PAI * ( DAVEAV / 2 0 ) **2*DELT *
     $ND*DELZI/VZ
      GMASS1=VMASS1+AMASS+CHMASS
      DELTGH=DELHH/(GMASS1*CPG)
      DELTWH=DELHH/(WMASS1*CPW)
      TG3=TG3-DELTGH
      TW3=TW3+DELTWH
      DELHET(J)=DELHH
      J=J+1
      IF(J.EQ.2) GO TO 10
      EROR=ABS(DELHET(J-1)-DELHET(J-2))
      EPS=0.0001
      IF(J.GT.50) GO TO 11
      IF(EROR.GT.EPS) GO TO 10
   11 RETURN
```

```
      END                                                               WICHET
I                                                                       WICHET
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ WICMAS
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICMAS
C                                                                      C WICMAS
C SUBROUTINE WICMAS                                                    C WICMAS
C                                                                      C WICMAS
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICMAS
      SUBROUTINE  WICMAS( HW1 , TW1 , TW2 , PP1 , PP2 , TG1 , TG2 , DZ , WICMAS
     1 PWB1 , PWB2 , PW1 , PW2 , VZ , DDAVE1 , DDAVE2 , HW2 , VMASS1 ,  WICMAS
     1 VMASS2 , WMASS1 , WMASS2 , DMDTAV , AMASS ,RE)                    WICMAS
      PWB1 = WICPWB(TW1)*144.0                                          WICMAS
      PWB2 = WICPWB( TW2 )*144.0                                        WICMAS
      PW1 = ( HW1 * PP1 ) / ( HW1 + 0.6219 )                            WICMAS
      DMDT1 = WICMTR( TG1 , TW1 , PP1 , DDAVE1 , VZ , DZ , WMASS1 ,     WICMAS
     1PW1 ,RE)                                                          WICMAS
      PW2AS1 = PW1                                                      WICMAS
      DMDT2 = WICMTR( TG 2 , TW 2 , PP2 , DDAVE2 , VZ , DZ , WMASS1 ,   WICMAS
     1PW2AS1 ,RE)                                                       WICMAS
      DMDTAV = ( DMDT1 + DMDT2 ) / 2.0                                  WICMAS
      VMASS2 = VMASS1 + DMDTAV                                          WICMAS
      WMASS2 = WMASS1 - DMDTAV                                          WICMAS
      HW2=VMASS2/AMASS                                                  WICMAS
      PW2CL1 = ( HW2 * PP2 ) / ( HW2 + 0.6219 )                         WICMAS
      PW2AS2 = PW1 * 1.05                                               WICMAS
      DMDT2 = WICMTR( TG2 , TW2 , PP2 , DDAVE2 , VZ , DZ , WMASS2 ,     WICMAS
     1PW2AS2 ,RE)                                                       WICMAS
      DMDTAV = ( DMDT1 + DMDT2 ) / 2.0                                  WICMAS
      VMASS2 = VMASS1 + DMDTAV                                          WICMAS
      WMASS2 = WMASS1 - DMDTAV                                          WICMAS
      HW2 = VMASS2 / AMASS                                              WICMAS
      PW2CL2 = ( HW2 * PP2 ) / ( HW2 + 0.6219 )                         WICMAS
    2 PW2ASN = WICNEW ( PW2AS1 , PW2CL1 , PW2AS2 , PW2CL2 )             WICMAS
      PW2AS1 = PW2AS2                                                   WICMAS
      PW2CL1 = PW2CL2                                                   WICMAS
      PW2AS2 = PW2ASN                                                   WICMAS
      DMDT2 = WICMTR( TG2 , TW2 , PP2 , DDAVE2 , VZ , DZ , WMASS2 , PW  WICMAS
     12AS2 ,RE)                                                         WICMAS
      DMDTAV = ( DMDT1 + DMDT2 ) / 2.0                                  WICMAS
      VMASS2 = VMASS1 + DMDTAV                                          WICMAS
      WMASS2 = WMASS1 - DMDTAV                                          WICMAS
      HW2 = VMASS2 / AMASS                                              WICMAS
      PW2CL2 = ( HW2 * PP2 ) / ( HW2 + 0.6219 )                         WICMAS
      ERROR = ABS ( PW2AS2 - PW2CL2 )                                   WICMAS
      EPS = 0.01                                                        WICMAS
      IF ( ERROR . GT . EPS ) GO TO 2                                   WICMAS
      PW2 = PW2AS2                                                      WICMAS
      RETURN                                                            WICMAS
      END                                                               WICMAS
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ WICMTR
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICMTR
C                                                                      C WICMTR
C FUNCTION WICMTR                                                      C WICMTR
C                                                                      C WICMTR
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICMTR
      FUNCTION WICMTR(TTG,TTW,PPP,DAVE,VZ,DZ,MMASS,PW,RE)               WICMTR
      REAL KG , ND , MMASS                                              WICMTR
      IF(DAVE.LT.1.0E-6) WICMTR=0.0                                     WICMTR
      IF(DAVE.LT.1.0E-6) GO TO 10                                       WICMTR
      DD=DAVE*1.0E-6*3.2802                                             WICMTR
      T = ( TTG + TTW ) / 2.0                                           WICMTR
      PAI = 3.1415926                                                   WICMTR
      RHOW = 62.2567                                                    WICMTR
      RR = DD / 2.0                                                     WICMTR
      TT = T * 5.0 / 9.0                                                WICMTR
      PP = PPP * 47.880258                                              WICMTR
      DV=4.24028E-3*(TT**1.5)/PP                                        WICMTR
      SCT=0.60                                                          WICMTR
      SH=2.0+0.60*SQRT(RE)*SCT**0.33                                    WICMTR
      KG = DV / DD * SH                                                 WICMTR
```

```
      HV=1115.3279-0.6840909*(TTW-460.0)                                  WICMTR
      PWBB=PW+29.0/18.0*0.45/HV*PPP*(TTG-TTW)                             WICMTR
      R = 85.78                                                           WICMTR
      ND = MMASS / ( RHOW * 4.0 / 3.0 * PAI * RR ** 3 )                   WICMTR
      WICMTR = KG * 4.0 * PAI * RR ** 2 * ( PWBB / TTW - PW / TTG ) / R   WICMTR
     1 * ND * DZ / VZ                                                     WICMTR
   10 RETURN                                                              WICMTR
      END                                                                 WICMTR
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++  WICPWB
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICPWB
C                                                                      C  WICPWB
C FUNCTION WICPWB                                                      C  WICPWB
C                                                                      C  WICPWB
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICPWB
      FUNCTION WICPWB(TWB)                                                WICPWB
      TSTAG=TWB                                                           WICPWB
      TSTAGC=(TSTAG-492.0)/1.8                                            WICPWB
      IF(TSTAGC.LT.100.0) GO TO 40                                        WICPWB
      IF(TSTAGC.GE.100.0.AND.TSTAGC.LT.200.0) GO TO 41                    WICPWB
      A=5.45142                                                           WICPWB
      B=2010.8                                                            WICPWB
      GO TO 42                                                            WICPWB
   40 A=5.9778                                                            WICPWB
      B=2224.4                                                            WICPWB
      GO TO 42                                                            WICPWB
   41 A=5.6485                                                            WICPWB
      B=2101.1                                                            WICPWB
   42 AA=A-B/(TSTAGC+273.0)                                               WICPWB
      PS=10.0**AA                                                         WICPWB
      PS=PS/4.88247E-4                                                    WICPWB
      WICPWB=PS/144.0                                                     WICPWB
      RETURN                                                              WICPWB
      END                                                                 WICPWB
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++  WICNEW
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICNEW
C                                                                      C  WICNEW
C FUNCTION WICNEW                                                      C  WICNEW
C                                                                      C  WICNEW
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICNEW
      FUNCTION WICNEW(X1,Y1,X2,Y2)                                        WICNEW
      T=ABS((X2-X1)/X1)                                                   WICNEW
      IF(T.LT.1.0E-6) WICNEW=(Y1+Y2)/2.0                                  WICNEW
      IF(T.LT.1.0E-6) GO TO 100                                           WICNEW
      A=(Y2-Y1)/(X2-X1)                                                   WICNEW
      B=Y1-A*X1                                                           WICNEW
      WICNEW=B/(1.0-A)                                                    WICNEW
  100 RETURN                                                              WICNEW
      END                                                                 WICNEW
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++  WICBPT
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICBPT
C                                                                      C  WICBPT
C FUNCTION WICBPT                                                      C  WICBPT
C                                                                      C  WICBPT
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICBPT
      FUNCTION WICBPT(TSTAG,PSTAG)                                        WICBPT
      TSTAGC=(TSTAG-492.0)/1.8                                            WICBPT
      IF(TSTAGC.LT.100.0) GO TO 20                                        WICBPT
      IF(TSTAGC.GE.100.0.AND.TSTAGC.LT.200.0) GO TO 21                    WICBPT
      A=5.45142                                                           WICBPT
      B=2010.8                                                            WICBPT
      GO TO 22                                                            WICBPT
   20 A=5.9778                                                            WICBPT
      B=2224.4                                                            WICBPT
      GO TO 22                                                            WICBPT
   21 A=5.6485                                                            WICBPT
      B=2101.1                                                            WICBPT
   22 PS=PSTAG*4.88247E-4                                                 WICBPT
      TBOILK=B/(A-ALOG10(PS))                                             WICBPT
      WICBPT=TBOILK*1.8                                                   WICBPT
      RETURN                                                              WICBPT
```

```
      END                                                               WICBPT
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++  WICSH
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICSH
C                                                                    C  WICSH
C FUNCTION WICSH                                                     C  WICSH
C                                                                    C  WICSH
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICSH
      FUNCTION WICSH(TSTAG,PSTAG)                                       WICSH
      TSTAGC=(TSTAG-492.0)/1.8                                          WICSH
      IF(TSTAGC.LT.100.0) GO TO 40                                      WICSH
      IF(TSTAGC.GE.100.0.AND.TSTAGC.LT.200.0) GO TO 41                  WICSH
      A=5.45142                                                         WICSH
      B=2010.8                                                          WICSH
      GO TO 42                                                          WICSH
   40 A=5.9778                                                          WICSH
      B=2224.4                                                          WICSH
      GO TO 42                                                          WICSH
   41 A=5.6485                                                          WICSH
      B=2101.1                                                          WICSH
   42 AA=A-B/(TSTAGC+273.0)                                             WICSH
      PS=10.0**AA                                                       WICSH
      PS=PS/4.88247E-4                                                  WICSH
      WICSH=0.6218847*PS/(PSTAG-PS)                                     WICSH
      RETURN                                                            WICSH
      END                                                               WICSH
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++  WICTAN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICTAN
C                                                                    C  WICTAN
C FUNCTION WICTAN                                                    C  WICTAN
C                                                                    C  WICTAN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICTAN
      FUNCTION WICTAN(X)                                                WICTAN
      A=COS(X)                                                          WICTAN
      B=SIN(X)                                                          WICTAN
      WICTAN=B/A                                                        WICTAN
      RETURN                                                            WICTAN
      END                                                               WICTAN
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++  WICCEN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICCEN
C                                                                    C  WICCEN
C SUBROUTINE WICCEN                                                  C  WICCEN
C                                                                    C  WICCEN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICCEN
      SUBROUTINE WICCEN(RZERO,UZERO,DD,VZ,DELZZ,ALFAAV,FN,IRS,RHOGAS,   WICCEN
     1RHUB,R2,U2,ITIP,VZTIME,XG,XA,XVV,XCH4,RTIPIN)                     WICCEN
      REAL N                                                            WICCEN
      PAI=3.1415926                                                     WICCEN
      ALFAAR=ALFAAV*PAI/180.0                                           WICCEN
      IF(DD.LT.1.0E-6) GO TO 12                                         WICCEN
      D=DD*1.0E-6*3.2802                                                WICCEN
      RHOA=RHOGAS                                                       WICCEN
      RHOD=62.37                                                        WICCEN
      XXAA=XA/XG                                                        WICCEN
      XXVV=XVV/XG                                                       WICCEN
      XXCC=XCH4/XG                                                      WICCEN
      VISCO=(XXAA*0.05715+XXVV*0.03293+XXCC*0.035)/3600.0               WICCEN
      ENDTIM=DELZZ/VZ                                                   WICCEN
      JJ=10                                                             WICCEN
      DELTIM=ENDTIM/FLOAT(JJ)                                           WICCEN
      R1=RZERO                                                          WICCEN
      U1=UZERO                                                          WICCEN
      TIME=0.0                                                          WICCEN
      JJJ=1                                                             WICCEN
   11 RE=D*U1/VISCO                                                     WICCEN
      B1=0.44                                                           WICCEN
      N=0.0                                                             WICCEN
      IF(RE.LT.1.9) B1=24.0                                             WICCEN
      IF(RE.LT.1.9) N=1.0                                               WICCEN
      IF(RE.GT.1.9.AND.RE.LT.500.0) B1=18.5                             WICCEN
      IF(RE.GT.1.9.AND.RE.LT.500.0) N=0.6                               WICCEN
```

```
      B=((VISCO**N)*B1*PAI*(RHOA**(1.0-N))*6.0)/(8.0*RHOD*PAI)           WICCEN
      C=B/(D**(1.0+N))                                                   WICCEN
      VW1=R1/12.0*2.0*PAI*FN/60.0                                        WICCEN
      IF(R1.GT.RTIPIN) VW1=RTIPIN/12.0*2.0*PAI*FN/60.0                   WICCEN
      VW2=VZ*WICTAN(ALFAAR)                                              WICCEN
      IF(ALFAAV.LT.1.0) VW=VW1                                           WICCEN
      IF(ALFAAV.GT.1.0) VW=VW1/2.0                                       WICCEN
      A=VW*VW*(1.0-RHOA/RHOD)                                            WICCEN
      DELU=(A/R1*12.0-C*U1**(2.0-N))*DELTIM                              WICCEN
      U2=U1+DELU                                                         WICCEN
      UAVE=U1+DELU/2.0                                                   WICCEN
      DELR=UAVE*DELTIM*12.0                                              WICCEN
      R2=R1+DELR                                                         WICCEN
      TIME=TIME+DELTIM                                                   WICCEN
      IPRINT=1                                                           WICCEN
      IF(IPRINT.EQ.2)                                                    WICCEN
     $WRITE(6,101) R1,VW,A,U1,DELU,U2,UAVE,DELR,R2,TIME                  WICCEN
  101 FORMAT(1H ,7(F11.4,2X),E10.4,2X,F10.4,2X,E10.4)                    WICCEN
      U1=U2                                                              WICCEN
      R1=R2                                                              WICCEN
      JJJ=JJJ+1                                                          WICCEN
      VZTIME=VZ*TIME*12.0                                                WICCEN
      IF(TIME.GT.ENDTIM) GO TO 12                                        WICCEN
      IF(JJJ.EQ.JJ) GO TO 12                                             WICCEN
      GO TO 11                                                           WICCEN
   12 RETURN                                                             WICCEN
      END                                                                WICCEN
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++     WICDMS
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICDMS
C                                                                      C WICDMS
C SUBROUTINE WICDMS                                                    C WICDMS
C                                                                      C WICDMS
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICDMS
      SUBROUTINE WICDMS(IPRINT,IRAD,AMASW1,AMASWT,AMASW,R1,R2,STAREA,    WICDMS
     $RSTAVE,RTIP,DMIN,DMOUT,AMASW2,DELMAS)                              WICDMS
      PAI=3.1415926                                                      WICDMS
      RST1=RSTAVE                                                        WICDMS
      A1=STAREA                                                          WICDMS
      A2=PAI*(R2**2-R1**2)/144.0                                         WICDMS
      A2=A2*0.5                                                          WICDMS
      DMCENT=A2/A1*AMASW                                                 WICDMS
  120 IF(DMCENT.LT.0.0) DMCENT=0.0                                       WICDMS
      IF(DMCENT.GT.AMASWT) DMCENT=AMASWT                                 WICDMS
      IF(R1.GT.RST1) GO TO 110                                           WICDMS
      DMIN=DMCENT                                                        WICDMS
      DMOUT=DMCENT                                                       WICDMS
      GO TO 100                                                          WICDMS
  110 CONTINUE                                                           WICDMS
      DMIN=0.0                                                           WICDMS
      DMOUT=DMCENT                                                       WICDMS
  100 IF(IRAD.EQ.1) DMOUT=0.0                                            WICDMS
      IF(IRAD.EQ.3) DMIN=0.0                                             WICDMS
      AMASW2=AMASW1+DMIN-DMOUT                                           WICDMS
      IF(AMASW2.LT.0.0) AMASW2=0.0                                       WICDMS
      IF(AMASW2.GT.AMASWT) AMASW2=AMASWT                                 WICDMS
      DELMAS=AMASW2-AMASW1                                               WICDMS
      IF(IPRINT.EQ.2) WRITE(6,200) AMASW2,AMASW1,DMIN,DMOUT,DMCENT,      WICDMS
     $AMASWT,AMASW,DELMAS                                                WICDMS
  200 FORMAT(1H0,8(F10.5,3X))                                            WICDMS
      RETURN                                                             WICDMS
      END                                                                WICDMS
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ WICDML
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICDML
C                                                                      C WICDML
C SUBROUTINE WICDML                                                    C WICDML
C                                                                      C WICDML
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICDML
      SUBROUTINE WICDML(IPRINT,IRAD,AMASW1,AMASWT,AMASW,R1,R2,STAREA,    WICDML
     $RSTAVE,RTIP,DMIN,DMOUT,AMASW2,DELMAS)                              WICDML
      PAI=3.1415926                                                      WICDML
```

```
      RST1=RSTAVE                                                       WICDML
      A1=STAREA                                                         WICDML
      A2=PAI*(R2**2-R1**2)/144.0                                        WICDML
      A2=A2*0.5                                                         WICDML
      DMCENT=A2/A1*AMASW                                                WICDML
  120 IF(DMCENT.LT.0.0) DMCENT=0.0                                      WICDML
      IF(DMCENT.GT.AMASWT) DMCENT=AMASWT                                WICDML
      IF(R1.GT.RST1) GO TO 110                                          WICDML
      DMIN=DMCENT                                                       WICDML
      DMOUT=DMCENT                                                      WICDML
      GO TO 100                                                         WICDML
  110 CONTINUE                                                          WICDML
      DMIN=0.0                                                          WICDML
      DMOUT=DMCENT                                                      WICDML
  100 IF(IRAD.EQ.1) DMOUT=0.0                                           WICDML
      IF(IRAD.EQ.3) DMIN=0.0                                            WICDML
      AMASW2=AMASW1+DMIN-DMOUT                                          WICDML
      IF(AMASW2.LT.0.0) AMASW2=0.0                                      WICDML
      IF(AMASW2.GT.AMASWT) AMASW2=AMASWT                                WICDML
      DELMAS=AMASW2-AMASW1                                              WICDML
      IF(IPRINT.EQ.2) WRITE(6,200) AMASW2,AMASW1,DMIN,DMOUT,DMCENT,     WICDML
     $AMASWT,AMASW,DELMAS                                               WICDML
  200 FORMAT(1H0,8(F10.5,3X))                                           WICDML
      RETURN                                                            WICDML
      END                                                               WICDML
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ WICDRG
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICDRG
C                                                                    C WICDRG
C SUBROUTINE WICDRG                                                   C WICDRG
C                                                                    C WICDRG
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC WICDRG
      SUBROUTINE WICDRG(D,DELV1,RHGAS1,RHGAS2,CD2,DELV2,DRAG1,RE)       WICDRG
      REAL N,N1                                                         WICDRG
      GC=32.174                                                         WICDRG
      IPRINT=1                                                          WICDRG
      VISCOG=12.0E-6                                                    WICDRG
      PAI=3.1415927                                                     WICDRG
      IF(D.GT.0.0) GO TO 300                                            WICDRG
      CD2=0.0                                                           WICDRG
      DELV2=0.0                                                         WICDRG
      DRAG1=0.0                                                         WICDRG
      RE=0.0                                                            WICDRG
      GO TO 301                                                         WICDRG
  300 RE1=(RHGAS1*D*DELV1)/VISCOG                                       WICDRG
      RE=RE1                                                            WICDRG
      B11=0.44                                                          WICDRG
      N1=0.0                                                            WICDRG
      IF(RE.LT.1.9) B11=24.0                                            WICDRG
      IF(RE.LT.1.9) N1=1.0                                              WICDRG
      IF(RE.GT.1.9.AND.RE.LT.500.0) B11=18.5                            WICDRG
      IF(RE.GT.1.9.AND.RE.LT.500.0) N1=0.6                              WICDRG
      CD1=B11/(RE1**N1)                                                 WICDRG
      DRAG1=0.5*RHGAS1*(DELV1**2)*(PAI*D**2)*CD1                        WICDRG
     $/GC                                                               WICDRG
      DAMY=DRAG1*GC/(CD1*0.5*RHGAS2*(PAI*D**2))                         WICDRG
      IF(IPRINT.EQ.2) WRITE(6,200) D,DELV1,RHGAS1,RHGAS2,RE1,B11,N1,    WICDRG
     $CD1,DRAG1,DAMY                                                    WICDRG
  200 FORMAT(1H0,10(F10.5,2X))                                          WICDRG
      DELV2=SQRT(DAMY)                                                  WICDRG
      RE2=RHGAS2*D*DELV2/VISCOG                                         WICDRG
      B1=0.44                                                           WICDRG
      N=0.0                                                             WICDRG
      IF(RE2.LT.1.9) B1=24.0                                            WICDRG
      IF(RE2.LT.1.9) N=1.0                                              WICDRG
      IF(RE2.GT.1.9.AND.RE2.LT.500.0) B1=18.5                           WICDRG
      IF(RE2.GT.1.9.AND.RE2.LT.500.0) N=0.6                             WICDRG
      CD2=B1/(RE2**N)                                                   WICDRG
      IF(IPRINT.EQ.2) WRITE(6,101) RE1,B11,N1,CD1,DELV1,RE2,B1,N,CD2,   WICDRG
     $DELV2                                                             WICDRG
  101 FORMAT(1H0,2X,10(F10.5,2X))                                       WICDRG
```

```
      RE=(RE1+RE2)/2.0
  301 RETURN
      END
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C SUBROUTINE WICSIZ                                                    C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE WICSIZ(WMASSL,WMASSS,AMING1,AMING2,AMING3,DL,DS,D1,D2,
     $D3,DLIMIT,AMSLL,AMLGE,DSLL,DLGE)
      TMASS1=WMASSL+WMASSS+AMING1+AMING2+AMING3
      AML=0.0
      AMS=0.0
      IF(DL.GT.DLIMIT) AML=AML+WMASSL
      IF(DL.LT.DLIMIT) AMS=AMS+WMASSL
      IF(DS.GT.DLIMIT) AML=AML+WMASSS
      IF(DS.LT.DLIMIT) AMS=AMS+WMASSS
      IF(D1.GT.DLIMIT) AML=AML+AMING1
      IF(D1.LT.DLIMIT) AMS=AMS+AMING1
      IF(D2.GT.DLIMIT) AML=AML+AMING2
      IF(D2.LT.DLIMIT) AMS=AMS+AMING2
      IF(D3.GT.DLIMIT) AML=AML+AMING3
      IF(D3.LT.DLIMIT) AMS=AMS+AMING3
      TMASS2=AML+AMS
      ERROR=ABS(TMASS1-TMASS2)
      IF(ERROR.LT.1.0E-6) GO TO 100
      IF(TMASS2.LT.1.0E-6) GO TO 100
      TT=TMASS1/TMASS2
      IF(TT.LT.1.0) AML=AML/TT
      IF(TT.LT.1.0) AMS=AMS/TT
      IF(TT.GT.1.0) AML=AML*TT
      IF(TT.GT.1.0) AMS=AMS*TT
  100 AMLGE=AML
      AMSLL=AMS
      ADL=0.0
      ADS=0.0
      IF(DL.GT.DLIMIT.AND.AML.GT.0.0) ADL=ADL+DL*(WMASSL/AML)
      IF(DL.LT.DLIMIT.AND.AMS.GT.0.0) ADS=ADS+DL*(WMASSL/AMS)
      IF(DS.GT.DLIMIT.AND.AML.GT.0.0) ADL=ADL+DS*(WMASSS/AML)
      IF(DS.LT.DLIMIT.AND.AMS.GT.0.0) ADS=ADS+DS*(WMASSS/AMS)
      IF(D1.GT.DLIMIT.AND.AML.GT.0.0) ADL=ADL+D1*(AMING1/AML)
      IF(D1.LT.DLIMIT.AND.AMS.GT.0.0) ADS=ADS+D1*(AMING1/AMS)
      IF(D2.GT.DLIMIT.AND.AML.GT.0.0) ADL=ADL+D2*(AMING2/AML)
      IF(D2.LT.DLIMIT.AND.AMS.GT.0.0) ADS=ADS+D2*(AMING2/AMS)
      IF(D3.GT.DLIMIT.AND.AML.GT.0.0) ADL=ADL+D3*(AMING3/AML)
      IF(D3.LT.DLIMIT.AND.AMS.GT.0.0) ADS=ADS+D3*(AMING3/AMS)
      DLGE=ADL
      DSLL=ADS
      IF(DL.GT.0.0.AND.DLGE.GT.DL) DLGE=DL
      IF(DS.GT.0.0.AND.DSLL.GT.DS) DSLL=DS
      RETURN
      END
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C SUBROUTINE WICPRP                                                    C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE WICPRP(XAIR,XH2O,XCH4,T,RMIX,CPMIX,GAMMA,G1,G2,G3)
C T IN R
C CPMIX IN BTU/LBM-R
C RMIX IN LBF-FT/LBM-R
      RAIR=1545.3/28.964
      RH2O=1545.3/18.016
      RCH4=1545.3/16.043
      XXAIR=XAIR/(XAIR+XH2O+XCH4)
      XXH2O=XH2O/(XAIR+XH2O+XCH4)
      XXCH4=XCH4/(XAIR+XH2O+XCH4)
      RMIX=XXAIR*RAIR+XXH2O*RH2O+XXCH4*RCH4
```

```
      CPMIX=XXAIR*WICCPA(T)+XXH2O*WICCPH(T)+XXCH4*WICCPC(T)             WICPRP
      GAMMA=1.0/(1.0-RMIX/CPMIX/778.0)                                  WICPRP
      G1=GAMMA/(GAMMA-1.0)                                              WICPRP
      G2=(GAMMA-1.0)/2.0                                                WICPRP
      G3=-1.0/(GAMMA-1.0)                                               WICPRP
      RETURN                                                            WICPRP
      END                                                               WICPRP
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++     WICCPA
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICCPA
C                                                                    C  WICCPA
C FUNCTION WICCPA                                                    C  WICCPA
C                                                                    C  WICCPA
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICCPA
      FUNCTION WICCPA(T)                                                WICCPA
C T IN R                                                                 WICCPA
C CPAIR IN BTU/LBM-R                                                     WICCPA
      TK=5.0/9.0*T                                                      WICCPA
      A=3.65359                                                         WICCPA
      B=-1.33736E-3                                                     WICCPA
      C=3.29421E-6                                                      WICCPA
      D=-1.91142E-9                                                     WICCPA
      E=0.275462E-12                                                    WICCPA
      R=8314.3/28.964                                                   WICCPA
      CP=(A+B*TK+C*TK**2+D*TK**3+E*TK**4)*R                             WICCPA
      WICCPA=CP*2.3885E-4                                               WICCPA
      RETURN                                                            WICCPA
      END                                                               WICCPA
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++     WICCPH
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICCPH
C                                                                    C  WICCPH
C FUNCTION WICCPH                                                    C  WICCPH
C                                                                    C  WICCPH
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICCPH
      FUNCTION WILCPH(T)                                                WICCPH
C T IN R                                                                 WICCPH
C CPH2O IN BTU/LBM-R                                                     WICCPH
      TK=5.0/9.0*T                                                      WICCPH
      A=4.07013                                                         WICCPH
      B=-1.10845E-3                                                     WICCPH
      C=4.15212E-6                                                      WICCPH
      D=-2.96374E-9                                                     WICCPH
      E=0.807021E-12                                                    WICCPH
      R=8314.3/18.016                                                   WICCPH
      CP=(A+B*TK+C*TK**2+D*TK**3+E*TK**4)*R                             WICCPH
      WICCPH=CP*2.3885E-4                                               WICCPH
      RETURN                                                            WICCPH
      END                                                               WICCPH
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++     WICCPC
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICCPC
C                                                                    C  WICCPC
C FUNCTION WICCPC                                                    C  WICCPC
C                                                                    C  WICCPC
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICCPC
      FUNCTION WICCPC(T)                                                WICCPC
C T IN R                                                                 WICCPC
C CPCH4 IN BTU/LBM-R                                                     WICCPC
      TK=5.0/9.0*T                                                      WICCPC
      A=3.82619                                                         WICCPC
      B=-3.97946E-3                                                     WICCPC
      C=24.5583E-6                                                      WICCPC
      D=-22.7329E-9                                                     WICCPC
      E=6.96270E-12                                                     WICCPC
      R=8314.3/16.043                                                   WICCPC
      CP=(A+B*TK+C*TK**2+D*TK**3+E*TK**4)*R                             WICCPC
      WICCPC=CP*2.3885E-4                                               WICCPC
      RETURN                                                            WICCPC
      END                                                               WICCPC
C ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++            WICGSL
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICGSL
C                                                                    C  WICGSL
```

```
C SUBROUTINE WICGSL                                                    C  WICGSL
C                                                                      C  WICGSL
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICGSL
      SUBROUTINE WICGSL(OMEGAS,SIGUMA,BET1S,BET2S,AINCIS,ADEVIS,AMACH1,   WICGSL
     1BET1,DEQS,DEQN,SITACS,SITACN,BET2N,OMEGAN,X,IDESIN,AK1,AK2,AK3      WICGSL
     2,VZ1,VZ2,UR1,R1,R2)                                                 WICGSL
      CALL WICEDD(AK3,VZ1,VZ2,UR1,R1,R2,BET1S,BET2S,SIGUMA,OMEGAS,        WICGSL
     $DEQS,SITACS)                                                        WICGSL
      AINCI=BET1-BET1S+AINCIS                                             WICGSL
      BET2A=BET2S                                                         WICGSL
      X1=BET2A                                                            WICGSL
      DELDEQ=WICED(AK3,VZ1,VZ2,UR1,R1,R2,BET1,X1,SIGUMA,AINCIS,AINCI)     WICGSL
     $-DEQS                                                               WICGSL
      ADEVI=ADEVIS+(6.40-9.45*AMACH1+9.45*X)*DELDEQ*AK1                   WICGSL
      IF(AMACH1.LT.X) ADEVI=ADEVIS+6.40*DELDEQ*AK1                        WICGSL
      BET2C=BET2S-ADEVIS+ADEVI                                            WICGSL
      Y1=BET2C                                                            WICGSL
      N=1                                                                 WICGSL
   12 IF(N.GT.1) GO TO 10                                                 WICGSL
      BET2A=BET2S*1.1                                                     WICGSL
   10 X2=BET2A                                                            WICGSL
      DEQN=WICED(AK3,VZ1,VZ2,UR1,R1,R2,BET1,X2,SIGUMA,AINCIS,AINCI)       WICGSL
      DELDEQ=DEQN-DEQS                                                    WICGSL
      ADEVI=ADEVIS+(6.40-9.45*AMACH1+9.45*X)*DELDEQ*AK1                   WICGSL
      IF(AMACH1.LT.X) ADEVI=ADEVIS+6.40*DELDEQ*AK1                        WICGSL
      BET2C=BET2S-ADEVIS+ADEVI                                            WICGSL
      Y2=BET2C                                                            WICGSL
      DELBET=ABS((X2-Y2)/X2)                                              WICGSL
      EPS=1.0E-6                                                          WICGSL
      IF(DELBET.LE.EPS) GO TO 11                                          WICGSL
      BET2A=WICNEW(X1,Y1,X2,Y2)                                           WICGSL
      X1=X2                                                               WICGSL
      Y1=Y2                                                               WICGSL
      N=N+1                                                               WICGSL
      IF(N.GT.50) GO TO 13                                                WICGSL
      GO TO 12                                                            WICGSL
   11 BET2N=X2                                                            WICGSL
      GO TO 14                                                            WICGSL
   13 WRITE(6,201)                                                        WICGSL
  201 FORMAT(1H0,≠DO NOT CONVERGE≠)                                       WICGSL
      GO TO 15                                                            WICGSL
   14 SITACN=WICMTK(SITACS,AMACH1,DELDEQ,AK2)                             WICGSL
      OMEGAN=WICLOS(BET1,BET2N,SIGUMA,SITACN)                             WICGSL
      SSS=SITACN-SITACS                                                   WICGSL
   15 RETURN                                                              WICGSL
      END                                                                 WICGSL
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++       WICSDL
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICSDL
C                                                                      C  WICSDL
C SUBROUTINE WICSDL                                                    C  WICSDL
C                                                                      C  WICSDL
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICSDL
      SUBROUTINE WICSDL(CHORD,SIGUMA,BETA1,BETA2,UG,RHOG,                 WICSDL
     $AMASSW,AREA,VZ,IPRINT,OMEGAP)                                       WICSDL
      PAI=3.1415926                                                       WICSDL
      RHOG0=RHOG                                                          WICSDL
      RHOP0=AMASSW/AREA/VZ                                                WICSDL
      RR=RHOP0/RHOG0                                                      WICSDL
      VISCOG=0.128E-4                                                     WICSDL
      C=CHORD/12.0                                                        WICSDL
      RE=UG*C*RHOG0/VISCOG                                                WICSDL
      DELC=0.37/(RE**0.2)/(1.0+1.442*RR)**0.8                             WICSDL
      DELP=0.1402*DELC                                                    WICSDL
      BETA1R=BETA1*PAI/180.0                                              WICSDL
      BETA2R=BETA2*PAI/180.0                                              WICSDL
      OMEGAP=DELP*2.0*SIGUMA/COS(BETA2R)*(COS(BETA1R)/COS(BETA2R))**2     WICSDL
      RETURN                                                              WICSDL
      END                                                                 WICSDL
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++   WICSTL
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICSTL
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C                                                                        C
C SUBROUTINE WICSTL                                                      C
C                                                                        C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE WICSTL(ISTAGE,IROTOR,DAV,W1,W2,DELV,V2,V3,WMASS,VZ,N
     $,BETA1,BETA2,ALFA2,ALFA3,MMASS,DELVU2,DELVL2,
     $OMEGRU,OMEGRL,OMEGSU,OMEGSL,DRAGRU,DRAGRL,DRAGSU,DRAGSL,REAVE)
      REAL M,MMASS
      COMMON TD(7),IUNIT
      COMMON CFL,CFT,CFP,CFD,CFM,CFV,CFA
      COMMON JPERFM,RHOG(3),RERUP,RERLOW,RESUP,RESLOW
      COMMON PREB,RRTIP(8),SRTIP(8),AAA1,AAA2,AAA3,SAREA(6),SAREAS(7)
      COMMON P(3),TG(3),XA,XV(3),XCH4,XW(3),XWW(3),XWT(3),TW(3),TWW(3)
      COMMON OMEGS(7),OMEGR(6),GAPR(6),GAPS(6)
      COMMON RRHUB(6) , RC(6) , RBLADE(6) , STAGER(6)
      COMMON SRHUB(7) , SC(7) , SBLADE(7),STAGES(7)
      COMMON SIGUMR(6) , BET1SR(6) , BET2SR(6) , AINCSR(6) , ADEVSR(6)
      COMMON SIGUMS(7) , BET1SS(7) , BET2SS(7) , AINCSS(7) , ADEVSS(7)
      COMMON UTIPG(6),UTIP(6),UTIPD(6),UOU(6),UMEAN(6),UHUB(6),U(6),FAI
      COMMON AREA(6),AREAS(7),UU2(6),UTIP2(6),UMEAN2(6),UHUB2(6),IPRINT
      COMMON ICENT,IICENT,FMR1(6),FMA2(6),IDESIN,FAID
      COMMON NS,NS1,RT(6),RM(6),RH(6),ST(6),SM(6),SH(6)
      COMMON DSMASS,AAREA(7),AAREAS(7),PR12D(6),PR13D(6),ETARD(6)
      COMMON UR(6),DS(6),DEQR(6),DEQS(6),BLOCK(6),BLOCKS(7)
      COMMON BET1MR(6),BET2MR(6),BET1MS(7),BET2MS(7),RADI1(6),RADI2(6)
      PAI=3.1415927
      GC=32.174
      RHOW=62.3
      IF(IROTOR.EQ.2) GO TO 100
C DROPLET DRAG IN ROTOR
      DD=DAV*1.0E-6*3.28
      VG1=W1
      VP1=VG1-DELV
      A1=WMASS*RC(ISTAGE)/12.0/VZ
      A2=RHOW*4.0/3.0*PAI*(DD/2.0)**3
      TN=0.0
      IF(WMASS.GT.0.0) GO TO 2000
      GO TO 2001
 2000 TN=A1/A2
 2001 VAVE=(W1+W2)/2.0
      GMU1=(90.0-BETA1)/2.0*PAI/180.0
      DELVU1=VG1-VP1*COS(GMU1)
      IF(N.GT.2) DELVU1=DELVU2
      TNU=TN*(180.0-BETA1-BETA2)/360.0
      XWW(2)=XWW(1)
      XWT(2)=XWT(1)
      CALL WICPRP(XA,XV(2),XCH4,TG(2),RMIX,CPMIX,GAMMA,G1,G2,G3)
      IF(IPRINT.EQ.2) WRITE(6,4000)
 4000 FORMAT(1H0,≠DROPLET DRAG IN ROTOR (UPPER PART)≠)
      CALL WICDRG(DD,DELVU1,RHOG(1),RHOG(2),CD2,DELV2,DRAG1,RE)
      DELVU2=DELV2
      CDRU=CD2
      RERUP=RE
      DRAGRU=DRAG1*TNU
      AREA1=PAI*(RRTIP(ISTAGE)**2-RRHUB(ISTAGE)**2)/144.0/10.0
      DELPRU=DRAGRU/AREA1
      OMEGRU=DELPRU/(0.5*RHOG(1)/GC*W1**2)
      CDRUU=CDRU*DELVU2**2*PAI/4.0*DD**2*TNU/VAVE**2/RC(ISTAGE)*12.0
      GML1=(90.0+BETA1)/2.0*PAI/180.0
      DELVL1=VG1-VP1*COS(GML1)
      IF(N.GT.2) DELVL1=DELVL2
      TNL=TN*(180.0+BETA1+BETA2)/360.0
      IF(IPRINT.EQ.2) WRITE(6,4001)
 4001 FORMAT(1H0,≠DROPLET DRAG IN ROTOR (LOWER PART)≠)
      CALL WICDRG(DD,DELVL1,RHOG(1),RHOG(2),CD2,DELV2,DRAG1,RE)
      DELVL2=DELV2
      CDRL=CD2
      RERLOW=RE
      DRAGRL=DRAG1*TNU
      DELPRL=DRAGRL/AREA1
```

```
      OMEGRL=DELPRL/(0.5*RHOG(1)/GC*W1**2)
      CDRLL=CDRL*DELVL2**2*PAI/4.0*DD**2*TNL/VAVE**2/RC(ISTAGE)*12.0
      IF(IPRINT.EQ.2) WRITE(6,2002)
 2002 FORMAT(1H0,≠DROPLET DRAG SUMMARY≠)
      IF(IPRINT.EQ.2) WRITE(6,720)DELVU1,DELVU2,DELVL1,DELVL2,CDRU,CD
     $RUU,CDRL,CDRLL
     $,DRAGRU,DRAGRL
  720 FORMAT(1H0,10(F10.5,2X))
      RUP1=(90.0-BETA1)/180.0
      RLOW1=(90.0+BETA1)/180.0
      RUP2=(90.0-BETA2)/180.0
      RLOW2=(90.0+BETA2)/180.0
      REAVE=RERUP*(RUP1+RUP2)*0.5+RERLOW*(RLOW1+RLOW2)*0.5
      IF(IPRINT.EQ.2) WRITE(6,2010) RUP1,RUP2,RLOW1,RLOW2
 2010 FORMAT(1H0,4(F10.5,2X))
      GO TO 200
C DROPLET DRAG IN STATOR
  100 DD=DAV*1.0E-6*3.28
      VG1=W1
      VP1=VG1-DELV
      A1=WMASS*SC(ISTAGE)/12.0/VZ
      A2=RHOW*4.0/3.0*PAI*(DD/2.0)**3
      TN=0.0
      IF(WMASS.GT.0.0) GO TO 5002
      GO TO 5003
 5002 TN=A1/A2
 5003 VAVE=(V3+V2)/2.0
      DELVU1=DELVU2
      TNU=TN*(180.0-ALFA2-ALFA3)/360.0
      IF(IPRINT.EQ.2) WRITE(6,2005)
 2005 FORMAT(1H0,≠DROPLET DRAG IN STATOR (UPPER PART)≠)
      CALL WICDRG(DD,DELVU1,RHOG(2),RHOG(2),CD2,DELV2,DRAG1,RE)
      DELVU2=DELV2
      CDSU=CD2
      RESUP=RE
      DRAGSU=DRAG1*TNU
      AREA2=PAI*(SRTIP(ISTAGE)**2-SRHUB(ISTAGE)**2)/144.0/10.0
      DELPSU=DRAGSU/AREA2
      OMEGSU=DELPSU/(0.5*RHOG(2)/GC*V2**2)
      CDSUU=CDSU*DELVU2**2*PAI/4.0*DD**2*TNU/VAVE**2/SC(ISTAGE)*12.0
      DELVL1=DELVL2
      TNL=TN*(180.0+ALFA2+ALFA3)/360.0
      IF(IPRINT.EQ.2) WRITE(6,2006)
 2006 FORMAT(1H0,≠DROPLET DRAG IN STATOR (LOWER PART)≠)
      CALL WICDRG(DD,DELVL1,RHOG(2),RHOG(2),CD2,DELV2,DRAG1,RE)
      DELVL2=DELV2
      CDSL=CD2
      RESLOW=RE
      DRAGSL=DRAG1*TNL
      DELPSL=DRAGSL/AREA2
      OMEGSL=DELPSL/(0.5*RHOG(2)/GC*V2**2)
      CDSLL=CDSL*DELVL2**2*PAI/4.0*DD**2*TNL/VAVE**2/SC(ISTAGE)*12.0
      IF(IPRINT.EQ.2) WRITE(6,2007)
 2007 FORMAT(1H0,≠DROPLET DRAG IN STATOR (SUMMARY)≠)
      IF(IPRINT.EQ.2)WRITE(6,721) DELVU1,DELVU2,DELVL1,DELVL2,CDSU,CD
     $SUU,CDSL,CDSLL
     ^,DRAGSU,DRAGSL
  721 FORMAT(1H0,10(F10.5,2X))
      SUP1=(90.0-ALFA2)/180.0
      SLOW1=(90.0+ALFA2)/180.0
      SUP2=(90.0-ALFA3)/180.0
      SLOW2=(90.0+ALFA3)/180.0
      REAVE=RESUP*(SUP1+SUP2)*0.5+RESLOW*(SLOW1+SLOW2)*0.5
      IF(IPRINT.EQ.2) WRITE(6,2011) SUP1,SUP2,SLOW1,SLOW2
 2011 FORMAT(1H0,4(F10.5,2X))
  200 RETURN
      END
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                     C
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C SUBROUTINE WICFML                                                    C  WICFML
C                                                                      C  WICFML
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICFML
      SUBROUTINE WICFML(WG1,WG2,FMASS,RHOG1,CHORD,SIGUMA,BETA1,BETA2,        WICFML
     $CDF,OMEGAF)                                                            WICFML
      PAI=3.1415926                                                          WICFML
      VISCOG=0.128E-4                                                        WICFML
      VISCOL=6.500E-4                                                        WICFML
      C=CHORD/12.0                                                           WICFML
      WGAVE=0.5*(WG1+WG2)                                                    WICFML
      VFILM=0.5*WGAVE*VISCOG/VISCOL                                          WICFML
      CDF=FMASS*VFILM/(0.5*RHOG1*WG1*WC1*C)                                  WICFML
      BETA1R=BETA1*PAI/180.0                                                 WICFML
      BETA2R=BETA2*PAI/180.0                                                 WICFML
      BETA3R=0.5*(BETA1R+BETA2R)                                             WICFML
      CS1=COS(BETA1R)**2                                                     WICFML
      CS2=COS(BETA3R)**3                                                     WICFML
      OMEGAF=CDF*SIGUMA*CS1/CS2                                              WICFML
      RETURN                                                                 WICFML
      END                                                                    WICFML
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++  WICRSL
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICRSL
C                                                                      C  WICRSL
C SUBROUTINE WICRSL                                                    C  WICRSL
C                                                                      C  WICRSL
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICRSL
      SUBROUTINE WICRSL(SIGUMA,BETA1,BETA2,CHORD,DL,CDR,OMEGAR)              WICRSL
      PAI=3.1415926                                                          WICRSL
      IF(DL.LT.1.0E-6) CDR=0.0                                               WICRSL
      IF(DL.LT.1.0E-6) OMEGAR=0.0                                            WICRSL
      IF(DL.LT.1.0E-6) GO TO 10                                              WICRSL
      BETA1R=BETA1*PAI/180.0                                                 WICRSL
      BETA2R=BETA2*PAI/180.0                                                 WICRSL
      BETA3R=0.5*(BETA1R+BETA2R)                                             WICRSL
      CS1=COS(BETA1R)**2                                                     WICRSL
      CS2=COS(BETA3R)**3                                                     WICRSL
      C=CHORD*2.54*0.01*1.0E6                                                WICRSL
      A=C/DL                                                                 WICRSL
      IF(A.LT.1000   ) A=1000                                                WICRSL
      CDR=1.89+1.62*ALOG10(A)                                                WICRSL
      CDR=1.0/CDR**2.5                                                       WICRSL
      OMEGAR=CDR*SIGUMA*CS1/CS2                                              WICRSL
   10 RETURN                                                                 WICRSL
      END                                                                    WICRSL
C +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++  WICUT
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICUT
C                                                                      C  WICUT
C SUBROUTINE WICUT                                                     C  WICUT
C                                                                      C  WICUT
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  WICUT
      SUBROUTINE WICUT(ISTAGE,ASPEED,ALFA1,VZ,V1,                            WICUT
     1VS1 , WS1 , BETA1, W1 , BETA2 , WS2 , VS2 , ALFA2 , W2 , V2 ,          WICUT
     1ALFA3 ,V3,AK1,AK3)                                                     WICUT
      COMMON TD(7),IUNIT                                                     WICUT
      COMMON CFL,CFT,CFP,CFD,CFM,CFU,CFA                                     WICUT
      COMMON JPERFM,RHOG(3),RERUP,RERLOW,RESUP,RESLOW                        WICUT
      COMMON FREE,RRTIP(8),SRTIP(8),AAA1,AAA2,AAA3,SAREA(6),SAREA3(7)        WICUT
      COMMON P(3),TG(3),XA,XV(3),XCH4,XW(3),XWW(3),XWT(3),TW(3),TWW(3)       WICUT
      COMMON OMEGS(7),OMEGR(6),GAPR(6),GAPS(6)                               WICUT
      COMMON RRHUB(6) , RC(6) , RBLADE(6) , STAGER(6)                        WICUT
      COMMON SRHUB(7) , SC(7) , SBLADE(7) , STAGES(7)                        WICUT
      COMMON SIGUMR(6) , BET1SR(6) , BET2SR(6) , AINCSR(6) , ADEVSR(6)       WICUT
      COMMON SIGUMS(7) , BET1SS(7) , BET2SS(7) , AINCSS(7) , ADEVSS(7)       WICUT
      COMMON UTIPG(6),UTIP(6),UTIPD(6),UOU(6),UMEAN(6),UHUB(6),U(6),FAI      WICUT
      COMMON AREA(6),AREAS(7),UU2(6),UTIP2(6),UMEAN2(6),UHUB2(6),IFRINT      WICUT
      COMMON ICENT,IICENT,FMA1(6),FMA2(6),IDESIN,FAID                        WICUT
      COMMON NS,NS1,RT(6),RM(6),RH(6),ST(6),SM(6),SH(6)                      WICUT
      COMMON DSMASS,AAREA(7),AAREAS(7),PR12D(6),PR13D(6),ETARD(6)            WICUT
      COMMON DR(6),DS(6),DEQR(6),DEQS(6),BLOCK(6),BLOCKS(7)                  WICUT
      COMMON BET1MR(6),BET2MR(6),BET1MS(7),BET2MS(7),RADI1(6),RADI2(6)       WICUT
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      PAI = 3.1415927
      ALFA1R = ALFA1 * PAI / 180.0
      V1 = VZ / COS ( ALFA1R )
      VS1 = VZ * TAN ( ALFA1R )
      WS1 = U(ISTAGE)- VS1
      T = WS1 / VZ
      BETA1R = ATAN ( T)
      BETA1 = BETA1R * 180.0 / PAI
      TT = VZ **2 + WS1 **2
      W1 = SQRT ( TT )
      AMACH1 = W1 / ASPEED
      CALL WICBOA (OMEGR(ISTAGE), SIGUMR ( ISTAGE ) , BET1SR ( ISTAGE
     1),BET2SR(ISTAGE),
     1  AINCSR ( ISTAGE ) , ADEVSR ( ISTAGE ) ,
     1AMACH1 , BETA1 , DEOS,DEON,SITACS,SITACN,BET2N ,FMR1(ISTAGE),
     1AK1,AK3,VZ,VZ,U(ISTAGE),RADI1(ISTAGE),RADI2(ISTAGE))
      BETA2 = BET2N
      BETA2R = BETA2 * PAI / 180.0
      WS2 = VZ * TAN ( BETA2R )
      VS2 = U(ISTAGE) - WS2
      TTT=VS2/VZ
      ALFA2R = ATAN ( TTT )
      ALFA2 = ALFA2R * 180.0 / PAI
      TTTT = VZ ** 2 + WS2 ** 2
      W2 = SQRT ( TTTT )
      TTTTT = VZ ** 2 + VS2 ** 2
      V2 = SQRT ( TTTTT )
      AMACH2 = V2 / ASPEED
      CALL WICBOA (OMEGS(ISTAGE), SIGUMS(ISTAGE)  , BET1SS(ISTAGE) ,
     1BET2SS ( ISTAGE ) , AINCSS ( ISTAGE ) , ADEVSS ( ISTAGE ),
     1AMACH2 , ALFA2 , DEOS,DEON,SITACS,SITACN,BET2N,FMA2(ISTAGE),
     1AK1,AK3,VZ,VZ,0.0,RADI2(ISTAGE),RADI1(ISTAGE+1))
      ALFA3 = BET2N
      ALFA3R=ALFA3*PAI/180.0
      V3=VZ/COS(ALFA3R)
      RETURN
      END
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                     C
C SUBROUTINE WICSPD                                                   C
C                                                                     C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE WICSPD(AMASS,ISTAGE)
      REAL M,MIN,M1,M2,M1REL,M2REL
      COMMON TD(7),IUNIT
      COMMON CFL,CFT,CFP,CFD,CFM,CFV,CFA
      COMMON JPERFM,RHUG(3),RERUP,RERLOW,RESUP,RESLOW
      COMMON PREB,RRTIP(8),SRTIP(8),AAA1,AAA2,AAA3,SAREA(6),SAREAS(7)
      COMMON P(3),TG(3),XA,XV(3),XCH4,XW(3),XWW(3),XWT(3),TW(3),TWW(3)
      COMMON OMEGS(7),OMEGR(6),GAPR(6),GAPS(6)
      COMMON RRHUB(6),RC(6),RBLADE(6),STAGER(6)
      COMMON SRHUB(7),SC(7),SBLADE(7),STAGES(7)
      COMMON SIGUMR(6),BET1SR(6),BET2SR(6),AINCSR(6),ADEVSR(6)
      COMMON SIGUMS(7),BET1SS(7),BET2SS(7),AINCSS(7),ADEVSS(7)
      COMMON UTIPC(6),UTIP(6),UTIPD(6),UOU(6),UMEAN(6),UHUB(6),U(6),FAI
      COMMON AREA(6),AREAS(7),UU2(6),UTIP2(6),UMEAN2(6),UHUB2(6),IPRINT
      COMMON ICENT,IICENT,FMR1(6),FMA2(6),IDESIN,FAID
      COMMON NS,NS1,RT(6),RM(6),RH(6),ST(6),SM(6),SH(6)
      COMMON DSMASS,AAREA(7),AAREAS(7),PR12D(6),PR13D(6),ETARD(6)
      COMMON DR(6),DS(6),DEQR(6),DEQS(6),BLOCK(6),BLOCKS(7)
      COMMON BET1MR(6),BET2MR(6),BET1MS(7),BET2MS(7),RADI1(6),RADI2(6)
      AJ=778.26
      PAI=3.1415926
      GC=32.174
      TREF=518.70
      PREF=14.7*144.0
      AAAR1T=PAI*(RRTIP(1)**2-RRHUB(1)**2)/144.0*BLOCK(1)
      CMASS=AMASS*SQRT(TG(1)/TREF)/(P(1)/PREF)*AAAR1T/SAREA(1)
C IGV INLET
```

```
      ISTAGE=NS1
      CALL WICPRP(1.0,0.0,0.0,TG(1),RMIX,CPMIX,GAMMA,G1,G2,G3)
      CALL WICMAC(ISTAGE,AMASS,TG(1),P(1),M,VZ,C,0.0,0.0,RMIX,CPMIX,ARE
     $AS(NS1))
      VZIN=VZ
      AIN=C
      MIN=M
      TOIN=TG(1)
      POIN=P(1)
      PSIN=P(1)/(1.0+G2*M**2)**G1
      TSIN=TG(1)/(1.0+G2*M**2)
      RHOGIN=PSIN/RMIX/TSIN
      FAIIN=VZIN/UTIPG(1)
      FAID=FAIIN
      GAMAIN=GAMMA
      TOIN=TG(1)
      POIN=P(1)
C IGV INLET PRINTOUT
      IF(IUNIT.NE.2) GO TO 861
      TOIN=TOIN*CFT
      POIN=POIN*CFP
      TSIN=TSIN*CFT
      PSIN=PSIN*CFP
      RHOGIN=RHOGIN*CFD
      AIN=AIN*CFV
      VZIN=VZIN*CFV
      AREAS(NS1)=AREAS(NS1)*CFA
  861 CONTINUE
      WRITE(6,1000)
 1000 FORMAT(1H1,≠**************** DESIGN POINT INFORMATION ************
     $****≠)
      WRITE(6,1010)
 1010 FORMAT(1H0,1X,≠****** COMPRESSOR INLET ******≠)
      WRITE(6,1020) TOIN,POIN,TSIN,PSIN,RHOGIN
 1020 FORMAT(1H0,1X,≠TOTAL TEMPERATURE AT COMPRESSOR INLET=≠,F10.5,/,
     $2X,≠TOTAL PRESSURE AT COMPRESSOR INLET=≠,F10.2,/,
     $2X,≠STATIC TEMPERATURE AT COMPRESSOR INLET=≠,F10.5,/,
     $2X,≠STATIC PRESSURE AT COMPRESSOR INLET=≠,F10.2,/,
     $2X,≠STATIC DENSITY AT COMPRESSOR INLET=≠,F10.5)
      WRITE(6,1030) AIN,VZIN,MIN,AREAS(NS1),FAIIN
 1030 FORMAT(1H0,1X,≠ACOUSTIC SPEED AT COMPRESSOR INLET=≠,F10.5,/,
     $2X,≠AXIAL VELOCITY AT COMPRESSOR INLET=≠,F10.5,/,
     $2X,≠MACH NUMBER AT COMPRESSOR INLET=≠,F10.5,/,
     $2X,≠STREAMTUBE AREA AT COMPRESSOR INLET=≠,F10.5,/,
     $2X,≠FLOW COEFFICIENT AT COMPRESSOR INLET=≠,F10.5)
      IF(IUNIT.NE.2) GO TO 862
      TOIN=TOIN/CFT
      POIN=POIN/CFP
      TSIN=TSIN/CFT
      PSIN=PSIN/CFP
      RHOGIN=RHOGIN/CFD
      AIN=AIN/CFV
      VZIN=VZIN/CFV
      AREAS(NS1)=AREAS(NS1)/CFA
  862 CONTINUE
C ROTOR INLET
      ISTAGE=1
  100 I=ISTAGE-1
      IF(I.EQ.0) I=NS1
      ALFA1=BET2SS(I)
      ADEVSS(I)=ALFA1-BET2MS(I)
      CALL WICMAC(ISTAGE,AMASS,TG(1),P(1),M,VZ,C,0.0,ALFA1,RMIX,
     $CPMIX,AREA(ISTAGE))
      CPMIX1=CPMIX
      GAMMA1=GAMMA
      VZ1=VZ
      A1=C
      M1=M
      PS1=P(1)/(1.0+G2*M1**2)**G1
      TS1=TG(1)/(1.0+G2*M1**2)
```

```
      RHOGS1=PS1/RMIX/TS1                                               WICSPD
      FAIRIN=VZ1/UTIPG(ISTAGE)                                          WICSPD
      ALFA1R=ALFA1*PAI/180.0                                            WICSPD
      V1=VZ1/COS(ALFA1R)                                                WICSPD
      VS1=VZ1*WICTAN(ALFA1R)                                            WICSPD
      WS1=U(ISTAGE)-VS1                                                 WICSPD
      WV=WS1/VZ1                                                        WICSPD
      BETA1R=ATAN(WV)                                                   WICSPD
      BETA1=BETA1R*180.0/PAI                                            WICSPD
      BET1SR(ISTAGE)=BETA1                                              WICSPD
      AINCSR(ISTAGE)=BETA1-BET1MR(ISTAGE)                               WICSPD
      W1=VZ1/COS(BETA1R)                                                WICSPD
      M1REL=W1/A1                                                       WICSPD
      TREL1=(1.0+G2*M1REL**2)*TS1                                       WICSPD
      PREL1=(1.0+G2*M1REL**2)**G1*PS1                                   WICSPD
      IF(ISTAGE.GE.2) DS(ISTAGE-1)=1.0-V1/V2+ABS(VS2-VS1)/2.0/          WICSPD
     $SIGUMS(ISTAGE-1)/V2                                               WICSPD
      IF(ISTAGE.GE.2) DEQS(ISTAGE-1)=COS(ALFA1R)/COS(ALFA2R)*           WICSPD
     $(1.12+0.61*COS(ALFA2R)**2/SIGUMS(ISTAGE-1)*(WICTAN(ALFA2R)-       WICSPD
     $WICTAN(ALFA1R)))                                                  WICSPD
      IF(ISTAGE.GT.NS) GO TO 101                                        WICSPD
C ROTOR OUTLET                                                          WICSPD
      P(2)=PR12D(ISTAGE)*P(1)                                           WICSPD
      TR12=(PR12D(ISTAGE)**(1.0/G1)-1.0)/ETARD(ISTAGE)+1.0              WICSPD
      TG(2)=TR12*TG(1)                                                  WICSPD
      CALL WICPRP(1.0,0.0,0.0,TG(2),RMIX,CPMIX,GAMMA,G1,G2,G3)          WICSPD
      GAMMA2=GAMMA                                                      WICSPD
      CPMIX2=CPMIX                                                      WICSPD
      GAMMAV=(GAMMA1+GAMMA2)/2.0                                        WICSPD
      CPMIXV=(CPMIX1+CPMIX2)/2.0                                        WICSPD
      G1AV=GAMMAV/(GAMMAV-1.0)                                          WICSPD
      G2AV=(GAMMAV-1.0)/2.0                                             WICSPD
      PR13I=(TG(2)/TG(1))**G1AV                                         WICSPD
      DELT=TG(2)-TG(1)                                                  WICSPD
      VS2=(U(ISTAGE)*VS1+DELT*CPMIXV*GC*AJ)/UU2(ISTAGE)                 WICSPD
      JJ=1                                                              WICSPD
      VZ2AS=VZ1                                                         WICSPD
  200 VS2VZ2=VS2/VZ2AS                                                  WICSPD
      ALFA2R=ATAN(VS2VZ2)                                               WICSPD
      ALFA2=ALFA2R*180.0/PAI                                            WICSPD
      BET1SS(ISTAGE)=ALFA2                                              WICSPD
      AINCSS(ISTAGE)=ALFA2-BET1MS(ISTAGE)                               WICSPD
      WS2=UU2(ISTAGE)-VS2                                               WICSPD
      WS2VZ2=WS2/VZ2AS                                                  WICSPD
      BETA2R=ATAN(WS2VZ2)                                               WICSPD
      BETA2=BETA2R*180.0/PAI                                            WICSPD
      BET2SR(ISTAGE)=BETA2                                              WICSPD
      ADEVSR(ISTAGE)=BETA2-BET2MR(ISTAGE)                               WICSPD
      V2=VZ2AS/COS(ALFA2R)                                              WICSPD
      W2=VZ2AS/COS(BETA2R)                                              WICSPD
      TS2=TG(2)-V2**2/(2.0*CPMIX2*GC*AJ)                                WICSPD
      A2=SQRT(GAMMA2*RMIX*TS2*GC)                                       WICSPD
      M2=V2/A2                                                          WICSPD
      PS2=P(2)/(1.0+G2*M2**2)**G1                                       WICSPD
      RHOGS2=PS2/RMIX/TS2                                               WICSPD
      M2REL=W2/A2                                                       WICSPD
      TREL2=(1.0+G2*M2REL**2)*TS2                                       WICSPD
      PREL2=(1.0+M2REL**2)**G1*PS2                                      WICSPD
      VZ2CL=FMASS/(RHOGS2*AREAS(ISTAGE))                                WICSPD
      EPS=1.0E-6                                                        WICSPD
      IF(JJ.EQ.2) GO TO 201                                             WICSPD
      IF(JJ.GT.2) GO TO 202                                             WICSPD
      X1=VZ2AS                                                          WICSPD
      Y1=VZ2CL                                                          WICSPD
      VZ2AS=VZ2CL                                                       WICSPD
      JJ=JJ+1                                                           WICSPD
      GO TO 200                                                         WICSPD
  201 X2=VZ2AS                                                          WICSPD
      Y2=VZ2CL                                                          WICSPD
      VZ2AS=WICNEW(X1,Y1,X2,Y2)                                         WICSPD
```

```
      JJ=JJ+1
      GO TO 200
  202 IF((ABS(VZ2AS-VZ2CL)/VZ2AS).LT.EPS) GO TO 300
      X1=X2
      Y1=Y2
      X2=VZ2AS
      Y2=VZ2CL
      VZ2AS=WICNEW(X1,Y1,X2,Y2)
      JJ=JJ+1
      GO TO 200
  300 VZ2=VZ2CL
      FAIOUT=VZ2/UTIPG(ISTAGE)
      DR(ISTAGE)=1.0-W2/W1+ABS(WS1-WS2)/2.0/SIGUMR(ISTAGE)/W1
      DEQR(ISTAGE)=COS(BETA2R)/COS(BETA1R)*
     $(1.12+0.61*COS(BETA1R)**2/SIGUMR(ISTAGE)*
     $(WICTAN(BETA1R)-WICTAN(BETA2R)))
      PRRELI=(1.0+C2AV*U(ISTAGE)**2/(GAMMAV*RMIX*TREL1*GC)
     $*((UU2(ISTAGE)/U(ISTAGE))**2-1.0))**G1AV
      PLOSSR=PR12D(ISTAGE)/(TG(2)/TG(1))**G1AV*PRRELI
      IF(PRRELI.LT.PLOSSR) PRRELI=1.0
      OMEGR(ISTAGE)=(PRRELI-PLOSSR)/(1.0-PS1/PREL1)
C STATOR OUTLET
      PLOSSS=PR13D(ISTAGE)/PR12D(ISTAGE)
      PR13=(TG(2)/TG(1))**G1AV*PLOSSR*PLOSSS/PRRELI
      OMEGS(ISTAGE)=(1.0-PLOSSS)/(1.0-PS2/P(2))
      ETASG=(PR13**(1.0/G1AV)-1.0)/(TR12-1.0)
      P(3)=PR13*P(1)
      TG(3)=TG(2)
      TD(ISTAGE)=TG(1)
C PRINTOUT OF STAGE PERFORMANCE
      IF(IUNIT.NE.2) GO TO 863
      TG(1)=TG(1)*CFT
      TG(2)=TG(2)*CFT
      P(1)=P(1)*CFP
      P(2)=P(2)*CFP
      TS1=TS1*CFT
      TS2=TS2*CFT
      PS1=PS1*CFP
      PS2=PS2*CFP
      RHOGS1=RHOGS1*CFD
      RHOGS2=RHOGS2*CFD
      VZ1=VZ1*CFV
      VZ2=VZ2*CFV
      V1=V1*CFV
      V2=V2*CFV
      W1=W1*CFV
      W2=W2*CFV
      VS1=VS1*CFV
      VS2=VS2*CFV
      WS1=WS1*CFV
      WS2=WS2*CFV
      U(ISTAGE)=U(ISTAGE)*CFV
      UU2(ISTAGE)=UU2(ISTAGE)*CFV
      TREL1=TREL1*CFT
      PREL1=PREL1*CFP
      TREL2=TREL2*CFT
      PREL2=PREL2*CFP
      AREA(ISTAGE)=AREA(ISTAGE)*CFA
      AREAS(ISTAGE)=AREAS(ISTAGE)*CFA
      RADI1(ISTAGE)=RADI1(ISTAGE)*CFL
      RADI2(ISTAGE)=RADI2(ISTAGE)*CFL
  863 CONTINUE
      WRITE(6,1000)
      WRITE(6,1100) ISTAGE
 1100 FORMAT(1H0,1X,≠***** STAGE=≠,I2,≠ ******≠)
      WRITE(6,1101)
 1101 FORMAT(1H0,16X,≠TOTAL≠,8X,≠TOTAL≠,7X,≠STATIC≠,7X,≠STATIC≠,7X,
     $≠STATIC≠,/,17X,≠TEMP≠,7X,≠PRESSURE≠,7X,≠TEMP≠,7X,≠PRESSURE≠,6X,
     $≠DENSITY≠)
      WRITE(6,1110) TG(1),P(1),TS1,PS1,RHOGS1
```

```
1110 FORMAT(1H0,1X,≠ROTOR INLET≠,1X,5(F10.3,3X))                            WICSPD
     WRITE(6,1120) TG(2),P(2),TS2,PS2,RHOGS2                                WICSPD
1120 FORMAT(1H ,1X,≠ROTOR OUTLET≠,5(F10.3,3X))                              WICSPD
     WRITE(6,1111)                                                          WICSPD
1111 FORMAT(1H0,16X,≠AXIAL≠,6X,≠ABSOLUTE≠,5X,≠RELATIVE≠,5X,≠TAN COMP≠,     WICSPD
    $5X,≠TAN COMP≠,/,15X,≠VELOCITY≠,5X,≠VELOCITY≠,5X,≠VELOCITY≠,4X,        WICSPD
    $≠OF ABS VEL≠,3X,≠OF REL VEL≠)                                          WICSPD
     WRITE(6,1130) VZ1,V1,W1,VS1,WS1                                        WICSPD
1130 FORMAT(1H0,1X,≠ROTOR INLET≠,1X,5(F10.5,3X))                            WICSPD
     WRITE(6,1140) VZ2,V2,W2,VS2,WS2                                        WICSPD
1140 FORMAT(1H ,1X,≠ROTOR OUTLET≠,5(F10.5,3X))                              WICSPD
     WRITE(6,1141)                                                          WICSPD
1141 FORMAT(1H0,15X,≠ROTOR≠,7X,≠ABS MACH≠,5X,≠REL MACH≠,5X,≠REL TOTAL≠,     WICSPD
    $4X,≠REL TOTAL≠,/,16X,≠SPEED≠,8X,≠NUMBER≠,7X,≠NUMBER≠,7X,≠TEMP≠,8X,    WICSPD
    $≠PRESSURE≠)                                                            WICSPD
     WRITE(6,1150) U(ISTAGE),M1,M1REL,TREL1,PREL1                           WICSPD
1150 FORMAT(1H0,1X,≠ROTOR INLET≠,1X,5(F10.3,3X))                            WICSPD
     WRITE(6,1160) UU2(ISTAGE),M2,M2REL,TREL2,PREL2                         WICSPD
1160 FORMAT(1H ,1X,≠ROTOR OUTLET≠,5(F10.3,3X))                              WICSPD
     I=ISTAGE                                                               WICSPD
     IF(ISTAGE.EQ.1) I=8                                                    WICSPD
     WRITE(6,1161)                                                          WICSPD
1161 FORMAT(1H0,14X,≠ABS FLOW≠,5X,≠REL FLOW≠,4X,≠STREAMTUBE≠,18X,           WICSPD
    $≠FLOW≠,/,16X,≠ANGLE≠,8X,≠ANGLE≠,8X,≠AREA≠,9X,≠RADIUS≠,5X,              WICSPD
    $≠COEFFICIENT≠)                                                         WICSPD
     WRITE(6,1170) BET2SS(I-1),BET1SR(ISTAGE),AREA(ISTAGE),                 WICSPD
    $RADI1(ISTAGE),FAIRIN                                                   WICSPD
1170 FORMAT(1H0,1X,≠ROTOR INLET≠,1X,5(F10.5,3X))                            WICSPD
     WRITE(6,1180) BET1SS(ISTAGE),BET2SR(ISTAGE),AREAS(ISTAGE),             WICSPD
    $RADI2(ISTAGE),FAIOUT                                                   WICSPD
1180 FORMAT(1H ,1X,≠ROTOR OUTLET≠,5(F10.5,3X))                              WICSPD
     WRITE(6,1190) PR13,ETASG,PR12D(ISTAGE),ETARD(ISTAGE),TR12              WICSPD
1190 FORMAT(1H0,1X,≠STAGE TOTAL PRESSURE RATIO AT DESIGN POINT=≠,F10.5,    WICSPD
    $/,2X,≠STAGE ADIABATIC EFFICIENCY AT DESIGN POINT=≠,F10.5,/,2X,         WICSPD
    $≠ROTOR TOTAL PRESSURE RATIO AT DESIGN POINT=≠,F10.5,/,2X,              WICSPD
    $≠ROTOR ADIABATIC EFFICIENCY AT DESIGN POINT=≠,F10.5,/,2X,              WICSPD
    $≠ROTOR TOTAL TEMPERATURE RATIO AT DESIGN POINT=≠,F10.5)                WICSPD
     IF(IUNIT.NE.2) GO TO 864                                               WICSPD
     TG(1)=TG(1)/CFT                                                        WICSPD
     TG(2)=TG(2)/CFT                                                        WICSPD
     P(1)=P(1)/CFP                                                          WICSPD
     P(2)=P(2)/CFP                                                          WICSPD
     TS1=TS1/CFT                                                            WICSPD
     TS2=TS2/CFT                                                            WICSPD
     PS1=PS1/CFP                                                            WICSPD
     PS2=PS2/CFP                                                            WICSPD
     RHOGS1=RHOGS1/CFD                                                      WICSPD
     RHOGS2=RHOGS2/CFD                                                      WICSPD
     VZ1=VZ1/CFV                                                            WICSPD
     VZ2=VZ2/CFV                                                            WICSPD
     V1=V1/CFV                                                              WICSPD
     V2=V2/CFV                                                              WICSPD
     W1=W1/CFV                                                              WICSPD
     W2=W2/CFV                                                              WICSPD
     VS1=VS1/CFV                                                            WICSPD
     VS2=VS2/CFV                                                            WICSPD
     WS1=WS1/CFV                                                            WICSPD
     WS2=WS2/CFV                                                            WICSPD
     U(ISTAGE)=U(ISTAGE)/CFV                                                WICSPD
     UU2(ISTAGE)=UU2(ISTAGE)/CFV                                            WICSPD
     TREL1=TREL1/CFT                                                        WICSPD
     PREL1=PREL1/CFP                                                        WICSPD
     TREL2=TREL2/CFT                                                        WICSPD
     PREL2=PREL2/CFP                                                        WICSPD
     AREA(ISTAGE)=AREA(ISTAGE)/CFA                                          WICSPD
     AREAS(ISTAGE)=AREAS(ISTAGE)/CFA                                        WICSPD
     RADI2(ISTAGE)=RADI2(ISTAGE)/CFL                                        WICSPD
 864 CONTINUE                                                               WICSPD
C REPEAT                                                                    WICSPD
     TG(1)=TG(3)                                                            WICSPD
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      P(1)=P(3)
      IF(ISTAGE.EQ.NS) ADEVSS(NS)=BET2SS(NS)-BET2MS(NS)
      ISTAGE=ISTAGE+1
      IF(ISTAGE.EQ.NS1) GO TO 101
      GO TO 100
C OVERALL PERFORMANCE AT DESIGN POINT
  101 OVALPR=P(3)/POIN
      OVALTR=TO(3)/TOIN
      GAMMAV=(GAMAIN+GAMMA)/2.0
      G1AV=GAMMAV/(GAMMAV-1.0)
      OVALEF=(OVALPR**(1.0/G1AV)-1.0)/(OVALTR-1.0)
      OVALDT=TO(3)-TOIN
C PRINTOUT OF OVERALL PERFORMANCE AT DESIGN POINT
      IF(IUNIT.NE.2) GO TO 865
      TOIN=TOIN*CFT
      POIN=POIN*CFP
      CMASS=CMASS*CFM
      OVALDT=OVALDT*CFT
      DO 422 I=1,NS
      TD(I)=TD(I)*CFT
  422 CONTINUE
  865 CONTINUE
      WRITE(6,1000)
      WRITE(6,421)
  421 FORMAT(1H0,≠*********** OVERALL PERFORMANCE AT DESIGN POINT ****
     $*******≠)
      WRITE(6,425) TOIN
  425 FORMAT(1H0,1X,≠COMPRESSOR INLET TOTAL TEMPERATURE=≠,F8.2)
      WRITE(6,426) POIN
  426 FORMAT(1H0,1X,≠COMPRESSOR INLET TOTAL PRESSURE=≠,F10.2)
      WRITE(6,427) CMASS
  427 FORMAT(1H0,1X,≠CORRECTED MASS FLOW RATE=≠,F6.3)
      WRITE(6,429) OVALPR
  429 FORMAT(1H0,1X,≠OVERALL TOTAL PRESSURE RATIO=≠,F6.4)
      WRITE(6,430) OVALTR
  430 FORMAT(1H0,1X,≠OVERALL TOTAL TEMPERATURE RATIO=≠,F6.4)
      WRITE(6,431) OVALEF
  431 FORMAT(1H0,1X,≠OVERALL ADIABATIC EFFICIENCY=≠,F6.4)
      WRITE(6,432) OVALDT
  432 FORMAT(1H0,1X,≠OVERALL TEMPERATURE RISE=≠,F8.3)
      WRITE(6,1621)
 1621 FORMAT(1H0,14X,≠1≠,5X,≠2≠,5X,≠3≠,5X,≠4≠,5X,≠5≠,5X,≠6≠,4X,≠IGV≠)
      WRITE(6,1710) (BET1SR(I),I=1,NS)
 1710 FORMAT(1H ,1X,≠BET1SR(I)≠,2X,6(F5.2,1X))
      WRITE(6,1720) (BET2SR(I),I=1,NS)
 1720 FORMAT(1H ,1X,≠BET2SR(I)≠,2X,6(F5.2,1X))
      WRITE(6,1730) (AINCSR(I),I=1,NS)
 1730 FORMAT(1H ,1X,≠AINCSR(I)≠,2X,6(F5.2,1X))
      WRITE(6,1740) (ADEVSR(I),I=1,NS)
 1740 FORMAT(1H ,1X,≠ADEVSR(I)≠,2X,6(F5.2,1X))
      WRITE(6,1760) (BET1SS(I),I=1,NS)
 1760 FORMAT(1H ,1X,≠BET1SS(I)≠,2X,6(F5.2,1X))
      WRITE(6,1770) (BET2SS(I),I=1,NS1)
 1770 FORMAT(1H ,1X,≠BET2SS(I)≠,2X,7(F5.2,1X))
      WRITE(6,1780) (AINCSS(I),I=1,NS)
 1780 FORMAT(1H ,1X,≠AINCSS(I)≠,2X,6(F5.2,1X))
      WRITE(6,1790) (ADEVSS(I),I=1,NS)
 1790 FORMAT(1H ,1X,≠ADEVSS(I)≠,2X,6(F5.2,1X))
      WRITE(6,1791) (TD(I),I=1,NS)
 1791 FORMAT(1H ,1X,≠TD(I)≠,6X,6(F5.1,1X))
      WRITE(6,1793) (OMEGS(I),I=1,NS)
 1793 FORMAT(1H ,1X,≠OMEGS(I)≠,3X,6(F5.3,1X))
      WRITE(6,1794) (OMEGR(I),I=1,NS)
 1794 FORMAT(1H ,1X,≠OMEGR(I)≠,3X,6(F5.3,1X))
      IF(IUNIT.NE.2) GO TO 866
      TOIN=TOIN/CFT
      POIN=POIN/CFP
      CMASS=CMASS/CFM
      OVALDT=OVALDT/CFT
      DO 423 I=1,NS
```

```
      TD(I)=TD(I)*CFT                                                   WICSPD     384
  423 CONTINUE                                                          WICSPD     385
  868 CONTINUE                                                          WICSPD     386
      RETURN                                                            WICSPD     387
      END                                                               WICSPD     388
```

APPENDIX 5

PRINTOUT OF TEST CASE

A.5.1 Test Case Part I

******************************** INPUT DATA **

NS(NUMBER OF STAGE)= 6
UNIT=ENGLISH UNIT
IPERFM=2
PERFORMANCE AT MEAN

	1	2	3	4	5	6	IGV
RRHUB(I)	.770	1.035	1.232	1.378	1.489	1.572	
RC(I)	.605	.554	.534	.510	.483	.456	
RBLADE(I)	16.00	20.00	20.00	25.00	28.00	32.00	
STAGER(I)	34.25	29.96	27.37	28.30	29.17	29.75	
STAGES(I)	23.67	25.62	26.94	28.41	29.82	38.99	
SRHUB(I)	.923	1.145	1.311	1.445	1.538	1.580	.774
SC(I)	.442	.412	.412	.412	.412	.412	
SBLADE(I)	14.00	26.00	28.00	32.00	36.00	30.00	
SIGUMR(I)	1.052	1.120	1.037	1.182	1.211	1.283	
SIGUMS(I)	.640	1.061	1.093	1.199	1.311	1.087	
GAPR(I)	.125	.125	.125	.125	.125	.125	
GAPS(I)	.125	.125	.125	.125	.125	.125	
RRTIP(I)	2.16	2.16	2.16	2.16	2.16	2.16	
SRTIP(I)	2.16	2.16	2.16	2.16	2.16	2.16	2.16
RT(I)	2.149	2.151	2.148	2.149	2.149	2.147	
RM(I)	1.426	1.575	1.642	1.722	1.789	1.836	
RH(I)	.781	1.056	1.252	1.411	1.533	1.621	
ST(I)	2.147	2.138	2.127	2.123	2.118	2.100	
SM(I)	1.502	1.573	1.637	1.712	1.766	1.784	
SH(I)	.934	1.152	1.318	1.453	1.548	1.592	
BLOCK(I)	.983	.976	.967	.949	.923	.902	
BLOCKS(I)	.978	.966	.945	.928	.908	.863	
BET1MR(I)	42.72	42.74	41.62	42.85	44.00	45.07	
BET2MR(I)	25.79	17.17	13.12	13.76	14.33	14.43	
BET1MS(I)	35.15	40.11	43.35	45.00	46.31	48.71	0
BET2MS(I)	12.19	11.13	10.51	11.81	13.32	29.28	21.99
PR12D(I)	1.154	1.165	1.221	1.237	1.230	1.215	
PR13D(I)	1.152	1.159	1.213	1.228	1.221	1.208	
ETARD(I)	.966	.966	.968	.965	.962	.954	

```
******************************* INPUT DATA *******************************

FNF(FRACTION OF DESIGN CORRECTED SPEED)=1.000

XDIN(INITIAL WATER CONTENT OF SMALL DROPLET)=    0
XDDIN(INITIAL WATER CONTENT OF LARGE DROPLET)=    0
RHUMID(INITIAL RELATIVE HUMIDITY)=   .00 PER CENT
XCH4(INITIAL METHANE CONTENT)=    0

TOG(COMPRESSOR INLET TOTAL TEMPRATURE OF GAS)= 518.70
TOW(COMPRESSOR INLET TEMPERATURE OF DROPLRET)= 513.70
PO(COMPRESSOR INLET TOTAL PRESSURE)=   2116.80

DIN(INITIIL DROPLET DIAMETER OF SMALL DROPLET)=  20.0
DDIN(INITIAL DROPLET DIAMETER OF LARGE DROPLET)= 600.0

FND(DESIGN ROTATIONAL SPEED)=51120.0

DSMASS(DESIGN MASS FLOW RATE)=      .3755

COMPRESSOR INLET TATAL TEMPERATURE(GAS PHASE) 518.70

COMPRESSOR INLET TOTAL PRESSURE=   2116.80

PREB(PERCENT OF WATER THAT REBOUND AFTER IMPINGE   MENT)= 50.0 PERCENT

ROTOR SPEED=51120.0 RPM

CORRECTED ROTOR SPEED= 51120.0 RPM(  100.0PER CENT OF DESIGN CORRECTED SPEED)
```

```
*************** DESIGN POINT INFORMATION ************ ***

 ***** COMPRESSOR INLET *****

 TOTAL TEMPERATURE AT COMPRESSOR INLET= 518.70000
 TOTAL PRESSURE AT COMPRESSOR INLET=   2116.80
 STATIC TEMPERATURE AT COMPRESSOR INLET= 496.28109
 STATIC PRESSURE AT COMPRESSOR INLET=   1813.73
 STATIC DENSITY AT COMPRESSOR INLET=    .06850

 ACOUSTIC SPEED AT COMPRESSOR INLET=1092.25914
 AXIAL VELOCITY AT COMPRESSOR INLET= 518.81873
 MACH NUMBER AT COMPRESSOR INLET=    .47500
 STREAMTUBE AREA AT COMPRESSOR INLET=    .01057
 FLOW COEFFICIENT AT COMPRESSOR INLET=    .53817
```

*************** DESIGN POINT INFORMATION ************ ***

***** STAGE= 1 *****

	TOTAL TEMP	TOTAL PRESSURE	STATIC TEMP	STATIC PRESSURE	STATIC DENSITY
ROTOR INLET	518.700	2116.800	492.637	1767.579	.067
ROTOR OUTLET	541.148	2442.787	508.269	1961.576	.072

	AXIAL VELOCITY	ABSOLUTE VELOCITY	RELATIVE VELOCITY	TAN COMP OF ABS VEL	TAN COMP OF REL VEL
ROTOR INLET	538.76531	559.39838	725.32398	150.52734	485.62003
ROTOR OUTLET	525.97105	628.55682	618.75550	344.14638	325.90306

	ROTOR SPEED	ABS MACH NUMBER	REL MACH NUMBER	REL TOTAL TEMP	REL TOTAL PRESSURE
ROTOR INLET	636.147	.514	.667	536.454	2381.210
ROTOR OUTLET	670.051	.569	.560	540.141	5091.790

	ABS FLOW ANGLE	REL FLOW ANGLE	STREAMTUBE AREA	RADIUS	FLOW COEFFICIENT
ROTOR INLET	15.61000	42.03015	.01036	1.42600	.55886
ROTOR OUTLET	33.19714	31.78325	.00987	1.50200	.54559

STAGE TOTAL PRESSURE RATIO AT DESIGN POINT= 1.15200
STAGE ADIABATIC EFFICIENCY AT DESIGN POINT= .95383
ROTOR TOTAL PRESSURE RATIO AT DESIGN POINT= 1.15400
ROTOR ADIABATIC EFFICIENCY AT DESIGN POINT= .96600
ROTOR TOTAL TEMPERATURE RATIO AT DESIGN POINT= 1.04329

*************** DESIGN POINT INFORMATION ************ ***

***** STAGE= 2 *****

	TOTAL TEMP	TOTAL PRESSURE	STATIC TEMP	STATIC PRESSURE	STATIC DENSITY
ROTOR INLET	541.148	2438.554	511.984	2008.852	.074
ROTOR OUTLET	566.141	2840.915	522.316	2142.394	.077

	AXIAL VELOCITY	ABSOLUTE VELOCITY	RELATIVE VELOCITY	TAN COMP OF ABS VEL	TAN COMP OF REL VEL
ROTOR INLET	549.21299	591.88727	730.68951	220.67086	481.94632
ROTOR OUTLET	581.16447	725.94045	639.44211	435.01464	266.71034

	ROTOR SPEED	ABS MACH NUMBER	REL MACH NUMBER	REL TOTAL TEMP	REL TOTAL PRESSURE
ROTOR INLET	702.617	.534	.659	556.431	2688.136
ROTOR OUTLET	701.725	.648	.571	556.331	5751.007

	ABS FLOW ANGLE	REL FLOW ANGLE	STREAMTUBE AREA	RADIUS	FLOW COEFFICIENT
ROTOR INLET	21.89000	41.26765	.00930	1.57500	.56970
ROTOR OUTLET	36.81569	24.65154	.00841	1.57300	.60285

STAGE TOTAL PRESSURE RATIO AT DESIGN POINT= 1.15900
STAGE ADIABATIC EFFICIENCY AT DESIGN POINT= .93231
ROTOR TOTAL PRESSURE RATIO AT DESIGN POINT= 1.16500
ROTOR ADIABATIC EFFICIENCY AT DESIGN POINT= .96600
ROTOR TOTAL TEMPERATURE RATIO AT DESIGN POINT= 1.04618

**************** DESIGN POINT INFORMATION ************ ***

***** STAGE= 3 *****

	TOTAL TEMP	TOTAL PRESSURE	STATIC TEMP	STATIC PRESSURE	STATIC DENSITY
ROTOR INLET	566.141	2826.284	535.362	2323.868	.081
ROTOR OUTLET	600.462	3450.892	549.786	2533.049	.086

	AXIAL VELOCITY	ABSOLUTE VELOCITY	RELATIVE VELOCITY	TAN COMP OF ABS VEL	TAN COMP OF REL VEL
ROTOR INLET	574.81563	608.26663	784.29006	198.93541	533.57089
ROTOR OUTLET	614.43880	781.11343	662.59507	482.28950	247.98627

	ROTOR SPEED	ABS MACH NUMBER	REL MACH NUMBER	REL TOTAL TEMP	REL TOTAL PRESSURE
ROTOR INLET	732.506	.536	.692	586.533	3199.070
ROTOR OUTLET	730.276	.680	.577	586.263	6929.751

	ABS FLOW ANGLE	REL FLOW ANGLE	STREAMTUBE AREA	RADIUS	FLOW COEFFICIENT
ROTOR INLET	19.09000	42.86892	.00803	1.64200	.59626
ROTOR OUTLET	38.12932	21.97990	.00708	1.63700	.63736

STAGE TOTAL PRESSURE RATIO AT DESIGN POINT= 1.21300
STAGE ADIABATIC EFFICIENCY AT DESIGN POINT= .93464
ROTOR TOTAL PRESSURE RATIO AT DESIGN POINT= 1.22100
ROTOR ADIABATIC EFFICIENCY AT DESIGN POINT= .96800
ROTOR TOTAL TEMPERATURE RATIO AT DESIGN POINT= 1.06062

*************** DESIGN POINT INFORMATION ************ ***

***** STAGE= 4 *****

	TOTAL TEMP	TOTAL PRESSURE	STATIC TEMP	STATIC PRESSURE	STATIC DENSITY
ROTOR INLET	600.462	3428.282	569.069	2839.989	.094
ROTOR OUTLET	639.381	4240.785	585.841	3118.959	.100

	AXIAL VELOCITY	ABSOLUTE VELOCITY	RELATIVE VELOCITY	TAN COMP OF ABS VEL	TAN COMP OF REL VEL
ROTOR INLET	580.04590	614.69778	809.54747	203.47020	564.72459
ROTOR OUTLET	619.63965	803.61317	668.93304	511.70446	252.02926

	ROTOR SPEED	ABS MACH NUMBER	REL MACH NUMBER	REL TOTAL TEMP	REL TOTAL PRESSURE
ROTOR INLET	768.195	.526	.692	623.519	3912.431
ROTOR OUTLET	763.734	.678	.564	622.951	8231.914

	ABS FLOW ANGLE	REL FLOW ANGLE	STREAMTUBE AREA	RADIUS	FLOW COEFFICIENT
ROTOR INLET	19.33000	44.23321	.00692	1.72200	.60169
ROTOR OUTLET	39.55025	22.13332	.00607	1.71200	.64276

STAGE TOTAL PRESSURE RATIO AT DESIGN POINT= 1.22800
STAGE ADIABATIC EFFICIENCY AT DESIGN POINT= .93002
ROTOR TOTAL PRESSURE RATIO AT DESIGN POINT= 1.23700
ROTOR ADIABATIC EFFICIENCY AT DESIGN POINT= .95500
ROTOR TOTAL TEMPERATURE RATIO AT DESIGN POINT= 1.06481

*************** DESIGN POINT INFORMATION ************ ***

***** STAGE= 5 *****

	TOTAL TEMP	TOTAL PRESSURE	STATIC TEMP	STATIC PRESSURE	STATIC DENSITY
ROTOR INLET	639.381	4209.930	606.962	3506.755	.108
ROTOR OUTLET	679.732	5178.214	625.197	3857.244	.116

	AXIAL VELOCITY	ABSOLUTE VELOCITY	RELATIVE VELOCITY	TAN COMP OF ABS VEL	TAN COMP OF REL VEL
ROTOR INLET	586.84149	625.22167	826.78513	215.68308	582.40082
ROTOR CUTLET	617.08868	811.98444	669.65381	527.75042	260.07304

	ROTOR SPEED	ABS MACH NUMBER	REL MACH NUMBER	REL TOTAL TEMP	REL TOTAL PRESSURE
ROTOR INLET	798.084	.518	.685	663.653	4798.526
ROTOR OUTLET	787.823	.663	.547	662.302	9691.778

	ABS FLOW ANGLE	REL FLOW ANGLE	STREAMTUBE AREA	RADIUS	FLOW COEFFICIENT
ROTOR INLET	20.16000	44.78240	.00591	1.78300	.60873
ROTOR OUTLET	40.53794	22.85308	.00526	1.76600	.64011

STAGE TOTAL PRESSURE RATIO AT DESIGN POINT= 1.22100
STAGE ADIABATIC EFFICIENCY AT DESIGN POINT= .32580
ROTOR TOTAL PRESSURE RATIO AT DESIGN POINT= 1.23000
ROTOR ADIABATIC EFFICIENCY AT DESIGN POINT= .96200
ROTOR TOTAL TEMPERATURE RATIO AT DESIGN POINT= 1.06311

*************** DESIGN POINT INFORMATION ************ ***

***** STAGE= 6 *****

	TOTAL TEMP	TOTAL PRESSURE	STATIC TEMP	STATIC PRESSURE	STATIC DENSITY
ROTOR INLET	679.732	5140.325	646.933	4318.954	.125
ROTOR OUTLET	720.259	6245.495	665.989	4736.291	.133

	AXIAL VELOCITY	ABSOLUTE VELOCITY	RELATIVE VELOCITY	TAN COMP OF ABS VEL	TAN COMP OF REL VEL
ROTOR INLET	587.19574	629.60666	833.74045	227.16890	591.88199
ROTOR OUTLET	603.39773	811.09676	654.61329	542.02320	253.83017

	ROTOR SPEED	ABS MACH NUMBER	REL MACH NUMBER	REL TOTAL TEMP	REL TOTAL PRESSURE
ROTOR INLET	819.051	.506	.669	704.449	5829.034
ROTOR OUTLET	795.853	.642	.518	701.350	10970.182

	ABS FLOW ANGLE	REL FLOW ANGLE	STREAMTUBE AREA	RADIUS	FLOW COEFFICIENT
ROTOR INLET	21.15000	45.22772	.00511	1.83600	.60910
ROTOR OUTLET	41.93288	22.81494	.00467	1.78400	.62591

STAGE TOTAL PRESSURE RATIO AT DESIGN POINT= 1.20800
STAGE ADIABATIC EFFICIENCY AT DESIGN POINT= .92365
ROTOR TOTAL PRESSURE RATIO AT DESIGN POINT= 1.21500
ROTOR ADIABATIC EFFICIENCY AT DESIGN POINT= .93400
ROTOR TOTAL TEMPERATURE RATIO AT DESIGN POINT= 1.05962

*************** DESIGN POINT INFORMATION ************ ***

********** OVERALL PERFORMANCE AT DESIGN POINT ****   ******

COMPRESSOR INLET TOTAL TEMPERATURE= 518.70

COMPRESSOR INLET TOTAL PRESSURE= 2116.80

CORRECTED MASS FLOW RATE= 3.168

OVERALL TOTAL PRESSURE RATIO=2.9334

OVERALL TOTAL TEMPERATURE RATIO=1.3886

OVERALL ADIABATIC EFFICIENCY= .9223

OVERALL TEMPERATURE RISE= 201.559

	1	2	3	4	5	6	IGV
BET1SR(I)	42.03	41.27	42.87	44.23	44.78	45.23	
BET2SR(I)	31.78	24.65	21.98	22.13	22.85	22.81	
AINCSR(I)	-.69	-1.47	1.25	1.38	.78	.16	
ADEVSR(I)	5.99	7.48	8.86	8.37	8.52	8.38	
BET1SS(I)	33.20	36.82	38.13	39.55	40.54	41.93	
BET2SS(I)	21.89	19.09	19.33	20.18	21.15	34.86	15.61
AINCSS(I)	-1.95	-3.29	-5.23	-5.45	-5.77	-6.78	
ADEVSS(I)	9.70	7.96	8.82	8.37	7.83	5.58	
TD(I)	518.7	541.1	566.1	600.5	639.4	679.7	
OMEGS(I)	.009	.021	.025	.028	.029	.024	
OMEGR(I)	.020	.021	.024	.028	.030	.036	

******************** INITIAL FLOW COEFFICIENT= .50000 (STAGE= 1) *******************

STAGE TOTAL PRESSURE RATIO= 1.18052
STAGE TOTAL TEMPERATURE RATIO= 1.05118
STAGE ADIABATIC EFFICIENCY= .94929

STAGE FLOW COEFFICIENT= .500
AXIAL VELOCITY= 482.12
ROTOR SPEED= 964.04

STAGE TOTAL PRESSURE RATIO(ACTUAL)= 1.18052
STAGE TOTAL PRESSURE RATIO(IDEAL)= 1.19072
LOSS FACTOR IN ROTOR= 1.01779
LOSS FACTOR IN STATOR= .99767

	ROTOR INLET	*ROTOR OUTLET*	*STATOR OUTLET*
TOTAL PRESSURE	2116.80	2504.78	2498.93
STATIC PRESSURE	1833.16	2064.66	2151.05
TOTAL TEMPERATURE(GAS)	518.7000	545.2462	545.2462
STATIC TEMPERATURE(GAS)	497.7954	515.9463	522.3760
STATIC DENSITY(GAS)	.0690	.0750	.0772
STATIC DENSITY(MIXTURE)	.0690	.0750	.0772
AXIAL VELOCITY	482.1211	465.8891	480.6390
ABSOLUTE VELOCITY	500.9898	593.2170	524.1017
RELATIVE VELOCITY	694.5426	555.6590	
BLADE SPEED	636.1474	670.0514	702.6172
TANG. COMP. OF ABS. VEL.	136.1987	367.2243	
TANG. COMP. OF REL. VEL.	499.9486	302.8271	
ACOUSTIC SPEED	1093.9243	1120.9182	1120.6073
ABSOLUTE MACH NUMBER	.4580	.5327	.4677
RELATIVE MACH NUMBER	.6349	.4989	
FLOW COEFFICIENT	.5001	.4833	.4986
FLOW AREA	.0104	.0099	.0093
ABSOLUTE FLOW ANGLE	15.7749	38.2460	23.5019
RELATIVE FLOW ANGLE	46.0400	33.0238	
INCIDENCE	3.3200	3.0960	
DEVIATION		7.2338	11.3119

******************** INITIAL FLOW COEFFICIENT= .50000 (ISTAGE= 1) ********************

STAGE PERFORMANCE AFTER INTER-STAGE ADJUSTMENT(JPERFM=2)

STAGE TOTAL PRESSURE RATIO= 1.18052
STAGE TOTAL TEMPERATURE RATIO= 1.05118
STAGE ADIABATIC EFFICIENCY= .94929

	STAGE INLET	**STAGE OUTLET** (BEFORE INTER-STAGE ADJUSTMENT)	**STAGE OUTLET** (AFTER INTER-STAGE ADJUSTMENT)
XV=	.00000	.00000	.00000
XW=	0	0	0
XWW=	0	0	0
XWT=	0	0	0
XAIR=	1.00000	1.00000	1.00000
XMETAN=	0	0	0
XGAS	1.00000	1.00000	1.00000
WMASS=	0	0	0
WWMASS=	0	0	0
WTMASS=	0	0	0
AMASS=	.34491	.34491	.34491
CHMASS=	0	0	0
VMASS=	.00000	.00000	.00000
GMASS=	.34491	.34491	.34491
TMASS=	.34491	.34491	.34491
WS=	.00000	.00000	.00000
RHOA=	.07649	.07500	.07718
RHOM=	.06904	.07500	.07718
RHOG=	.06902	.07500	.07718
TG=	518.70000	545.24617	545.24617
TW=	513.70000	513.70000	513.70000
TWW=	513.70000	0	513.70000
P=	2116.80000	2504.77696	2498.92898
TB=	671.40656	0	679.62039
TDEW=	271.99506	273.35228	273.35228

******************** INITIAL FLOW COEFFICIENT= .50000 (STAGE= 2) ********************

STAGE TOTAL PRESSURE RATIO= 1.18150
STAGE TOTAL TEMPERATURE RATIO= 1.05273
STAGE ADIABATIC EFFICIENCY= .92538

STAGE FLOW COEFFICIENT= .499
AXIAL VELOCITY= 480.65
ROTOR SPEED= 964.04

STAGE TOTAL PRESSURE RATIO(ACTUAL)= 1.18150
STAGE TOTAL PRESSURE RATIO(IDEAL)= 1.19700
LOSS FACTOR IN ROTOR= .99305
LOSS FACTOR IN STATOR= .99331

	ROTOR INLET	*ROTOR OUTLET*	*STATOR OUTLET*
TOTAL PRESSURE	2498.93	2972.36	2952.48
STATIC PRESSURE	2151.02	2334.66	2553.83
TOTAL TEMPERATURE(GAS)	545.2462	573.9966	573.9966
STATIC TEMPERATURE(GAS)	522.3793	535.7319	550.6973
STATIC DENSITY(GAS)	.0772	.0817	.0869
STATIC DENSITY(MIXTURE)	.0772	.0817	.0869
AXIAL VELOCITY	480.6495	502.3934	494.1596
ABSOLUTE VELOCITY	524.1276	678.1185	529.1491
RELATIVE VELOCITY	688.9633	559.5039	
BLADE SPEED	702.6172	701.7250	732.5063
TANG. COMP. OF ABS. VEL.	209.0116	455.4619	
TANG. COMP. OF REL. VEL.	493.6056	246.2631	
ACOUSTIC SPEED	1120.4811	1150.2843	1150.4507
ABSOLUTE MACH NUMBER	.4678	.5976	.4599
RELATIVE MACH NUMBER	.6149	.4931	
FLOW COEFFICIENT	.4986	.5211	.5126
FLOW AREA	.0093	.0084	.0080
ABSOLUTE FLOW ANGLE	23.5019	42.1950	20.9539
RELATIVE FLOW ANGLE	45.7619	26.1132	
INCIDENCE	3.0219	2.0850	
DEVIATION		8.9432	9.8239

******************** INITIAL FLOW COEFFICIENT= .50000 (ISTAGE= 2) ********************

STAGE PERFORMANCE AFTER INTER-STAGE ADJUSTMENT(JPERFM=2)

STAGE TOTAL PRESSURE RATIO= 1.18150
STAGE TOTAL TEMPERATURE RATIO= 1.05273
STAGE ADIABATIC EFFICIENCY= .92538

	STAGE INLET	**STAGE OUTLET** (BEFORE INTER-STAGE ADJUST-MENT)	**STAGE OUTLET** (AFTER INTER-STAGE ADJUST-MENT)
XV=	.00000	.00000	.00000
XW=	0	0	0
XWW=	0	0	0
XWT=	0	0	0
XAIR=	1.00000	1.00000	1.00000
XMETAN=	0	0	0
XGAS	1.00000	1.00000	1.00000
WMASS=	0	0	0
WWMASS=	0	0	0
WTMASS=	0	0	0
AMASS=	.34491	.34491	.34491
CHMASS=	0	0	0
VMASS=	.00000	.00000	.00000
GMASS=	.34491	.34491	.34491
TMASS=	.34491	.34491	.34491
WS=	.00000	.00000	.00000
RHOA=	.08590	.08168	.08692
RHOM=	.06904	.08168	.08692
RHOG=	.07718	.08168	.08692
TG=	545.24617	573.99661	573.99661
TW=	513.70000	513.70000	513.70000
TWW=	513.70000	0	513.70000
P=	2498.92898	2972.35955	2952.48188
TB=	679.62039	0	688.08016
TDEW=	273.35228	274.74655	274.74655

******************** INITIAL FLOW COEFFICIENT= .50000 (STAGE= 3) ******************

STAGE TOTAL PRESSURE RATIO= 1.22966
STAGE TOTAL TEMPERATURE RATIO= 1.06596
STAGE ADIABATIC EFFICIENCY= .92118

STAGE FLOW COEFFICIENT= .513
AXIAL VELOCITY= 494.17
ROTOR SPEED= 964.04

STAGE TOTAL PRESSURE RATIO(ACTUAL)= 1.22966
STAGE TOTAL PRESSURE RATIO(IDEAL)= 1.25071
LOSS FACTOR IN ROTOR= .99061
LOSS FACTOR IN STATOR= .99091

	ROTOR INLET	*ROTOR OUTLET*	*STATOR OUTLET*
TOTAL PRESSURE	2952.48	3663.87	3630.55
STATIC PRESSURE	2553.80	2827.58	3166.80
TOTAL TEMPERATURE(GAS)	573.9966	611.8566	611.8566
STATIC TEMPERATURE(GAS)	550.7079	568.2392	588.4487
STATIC DENSITY(GAS)	.0869	.0933	.1009
STATIC DENSITY(MIXTURE)	.0869	.0933	.1009
AXIAL VELOCITY	494.1744	522.5140	494.0333
ABSOLUTE VELOCITY	529.1692	724.3096	530.6107
RELATIVE VELOCITY	734.4023	570.3622	
BLADE SPEED	732.5063	730.2758	768.1948
TANG. COMP. OF ABS. VEL.	189.2399	501.6010	
TANG. COMP. OF REL. VEL.	543.2664	228.6748	
ACOUSTIC SPEED	1150.2627	1188.4867	1189.0241
ABSOLUTE MACH NUMBER	.4600	.6199	.4463
RELATIVE MACH NUMBER	.6385	.4881	
FLOW COEFFICIENT	.5126	.5420	.5125
FLOW AREA	.0080	.0071	.0069
ABSOLUTE FLOW ANGLE	20.9539	43.8301	21.4115
RELATIVE FLOW ANGLE	47.7092	23.6363	
INCIDENCE	6.0892	.4701	
DEVIATION		10.5163	10.9015

******************** INITIAL FLOW COEFFICIENT= .50000 (ISTAGE= 3) ********************

STAGE PERFORMANCE AFTER INTER-STAGE ADJUSTMENT(JPERFM=2)

STAGE TOTAL PRESSURE RATIO= 1.22966
STAGE TOTAL TEMPERATURE RATIO= 1.06596
STAGE ADIABATIC EFFICIENCY= .92118

	STAGE INLET	**STAGE OUTLET** (BEFORE INTER-STAGE ADJUSTMENT)	**STAGE OUTLET** (AFTER INTER-STAGE ADJUSTMENT)
XU=	.00000	.00000	.00000
XW=	0	0	0
XWW=	0	0	0
XWT=	0	0	0
XAIR=	1.00000	1.00000	1.00000
XMETAN=	0	0	0
XGAS	1.00000	1.00000	1.00000
WMASS=	0	0	0
WWMASS=	0	0	0
WTMASS=	0	0	0
AMASS=	.34491	.34491	.34491
CHMASS=	0	0	0
VMASS=	.00000	.00000	.00000
GMASS=	.34491	.34491	.34491
TMASS=	.34491	.34491	.34491
WS=	.00000	.00000	.00000
RHOA=	.09641	.09326	.10086
RHOM=	.06904	.09326	.10086
RHOG=	.08692	.09326	.10086
TG=	573.99661	611.85659	611.85659
TW=	513.70000	513.70000	513.70000
TWW=	513.70000	0	513.70000
P=	2952.48188	3663.87348	3630.55342
TB=	688.08016	0	698.86348
TDEW=	274.74655	276.46988	276.46988

****************** INITIAL FLOW COEFFICIENT= .50000 (STAGE= 4) ******************

STAGE TOTAL PRESSURE RATIO= 1.24218
STAGE TOTAL TEMPERATURE RATIO= 1.06978
STAGE ADIABATIC EFFICIENCY= .91298

STAGE FLOW COEFFICIENT= .513
AXIAL VELOCITY= 494.07
ROTOR SPEED= 964.04

STAGE TOTAL PRESSURE RATIO(ACTUAL)= 1.24218
STAGE TOTAL PRESSURE RATIO(IDEAL)= 1.26694
LOSS FACTOR IN ROTOR= .98759
LOSS FACTOR IN STATOR= .98968

	ROTOR INLET	*ROTOR OUTLET*	*STATOR OUTLET*
TOTAL PRESSURE	3630.55	4556.82	4509.80
STATIC PRESSURE	3166.66	3525.69	3957.68
TOTAL TEMPERATURE(GAS)	611.8566	654.5529	654.5529
STATIC TEMPERATURE(GAS)	588.4681	608.4010	630.6384
STATIC DENSITY(GAS)	.1009	.1086	.1176
STATIC DENSITY(MIXTURE)	.1009	.1086	.1176
AXIAL VELOCITY	494.0715	522.8404	496.2018
ABSOLUTE VELOCITY	530.6990	745.6155	536.7235
RELATIVE VELOCITY	757.6978	572.0630	
BLADE SPEED	768.1948	763.7337	798.0839
TANG. COMP. OF ABS. VEL.	193.7390	531.5829	
TANG. COMP. OF REL. VEL.	574.4558	232.1508	
ACOUSTIC SPEED	1188.6880	1230.0789	1230.5425
ABSOLUTE MACH NUMBER	.4465	.6169	.4362
RELATIVE MACH NUMBER	.6374	.4733	
FLOW COEFFICIENT	.5125	.5423	.5147
FLOW AREA	.0069	.0061	.0059
ABSOLUTE FLOW ANGLE	21.4115	45.4750	22.4163
RELATIVE FLOW ANGLE	49.3022	23.9421	
INCIDENCE	6.4522	.4750	
DEVIATION		10.1821	10.6063

******************** INITIAL FLOW COEFFICIENT= .50000 (ISTAGE= 4) ********************

STAGE PERFORMANCE AFTER INTER-STAGE ADJUSTMENT(JPERFM=2)

STAGE TOTAL PRESSURE RATIO= 1.24218
STAGE TOTAL TEMPERATURE RATIO= 1.06978
STAGE ADIABATIC EFFICIENCY= .91298

	STAGE INLET	**STAGE OUTLET** (BEFORE INTER-STAGE ADJUSTMENT)	**STAGE OUTLET** (AFTER INTER-STAGE ADJUSTMENT)
XV=	.00000	.00000	.00000
XW=	0	0	0
XWW=	0	0	0
XWT=	0	0	0
XAIR=	1.00000	1.00000	1.00000
XMETAN=	0	0	0
XGAS	1.00000	1.00000	1.00000
WMASS=	0	0	0
WWMASS=	0	0	0
WTMASS=	0	0	0
AMASS=	.34491	.34491	.34491
CHMASS=	0	0	0
VMASS=	.00000	.00000	.00000
GMASS=	.34491	.34491	.34491
TMASS=	.34491	.34491	.34491
WS=	.00000	.00000	.00000
RHOA=	.11122	.10860	.11762
RHOM=	.06904	.10860	.11762
RHOG=	.10086	.10860	.11762
TG=	611.85659	654.55293	654.55293
TW=	513.70000	513.70000	513.70000
TWW=	513.70000	0	513.70000
P=	3630.55342	4556.82036	4509.79574
TB=	698.86348	0	710.54436
TDEW=	276.46988	278.29004	278.29004

******************** INITIAL FLOW COEFFICIENT= .50000 (STAGE= 5) ******************

STAGE TOTAL PRESSURE RATIO= 1.23414
STAGE TOTAL TEMPERATURE RATIO= 1.06793
STAGE ADIABATIC EFFICIENCY= .90663

STAGE FLOW COEFFICIENT= .515
AXIAL VELOCITY= 496.25
ROTOR SPEED= 964.04

STAGE TOTAL PRESSURE RATIO(ACTUAL)= 1.23414
STAGE TOTAL PRESSURE RATIO(IDEAL)= 1.25990
LOSS FACTOR IN ROTOR= .98308
LOSS FACTOR IN STATOR= .98949

	ROTOR INLET	*ROTOR OUTLET*	*STATOR OUTLET*
TOTAL PRESSURE	4509.80	5624.85	5565.72
STATIC PRESSURE	3957.52	4401.30	4921.73
TOTAL TEMPERATURE(GAS)	654.5529	699.0183	699.0183
STATIC TEMPERATURE(GAS)	630.6739	651.9165	674.9958
STATIC DENSITY(GAS)	.1176	.1265	.1367
STATIC DENSITY(MIXTURE)	.1176	.1265	.1367
AXIAL VELOCITY	496.2499	517.9326	493.7867
ABSOLUTE VELOCITY	536.8130	754.0599	538.5133
RELATIVE VELOCITY	773.5389	570.7437	
BLADE SPEED	798.0839	787.8235	819.0509
TANG. COMP. OF ABS. VEL.	204.7050	548.0439	
TANG. COMP. OF REL. VEL.	593.3789	239.7796	
ACOUSTIC SPEED	1230.0502	1272.1584	1272.5386
ABSOLUTE MACH NUMBER	.4364	.6030	.4232
RELATIVE MACH NUMBER	.6289	.4564	
FLOW COEFFICIENT	.5148	.5373	.5122
FLOW AREA	.0059	.0053	.0051
ABSOLUTE FLOW ANGLE	22.4163	46.6180	23.5232
RELATIVE FLOW ANGLE	50.0939	24.8420	
INCIDENCE	6.0939	.3080	
DEVIATION		10.5120	10.2032

******************** INITIAL FLOW COEFFICIENT= .50000 (ISTAGE= 5) ********************

STAGE PERFORMANCE AFTER INTER-STAGE ADJUSTMENT(JPERFM=2)

STAGE TOTAL PRESSURE RATIO= 1.23414
STAGE TOTAL TEMPERATURE RATIO= 1.06793
STAGE ADIABATIC EFFICIENCY= .90663

	STAGE INLET	**STAGE OUTLET** (BEFORE INTER-STAGE ADJUSTMENT)	**STAGE OUTLET** (AFTER INTER-STAGE ADJUSTMENT)
XU=	.00000	.00000	.00000
XW=	0	0	0
XWW=	0	0	0
XWT=	0	0	0
XAIR=	1.00000	1.00000	1.00000
XMETAN=	0	0	0
XGAS	1.00000	1.00000	1.00000
WMASS=	0	0	0
WWMASS=	0	0	0
WTMASS=	0	0	0
AMASS=	.34491	.34491	.34491
CHMASS=	0	0	0
VMASS=	.00000	.00000	.00000
GMASS=	.34491	.34491	.34491
TMASS=	.34491	.34491	.34491
WS=	.00000	.00000	.00000
RHOA=	.12914	.12651	.13665
RHOM=	.06904	.12651	.13665
RHOG=	.11762	.12651	.13665
TG=	654.55293	699.01831	699.01831
TW=	513.70000	513.70000	513.70000
TWW=	513.70000	0	513.70000
P=	4509.79574	5624.84868	5565.71763
TB=	710.54436	0	725.30379
TDEW=	278.29004	270.78298	270.78298

******************** INITIAL FLOW COEFFICIENT= .50000 (STAGE= 6) ********************

STAGE TOTAL PRESSURE RATIO= 1.21895
STAGE TOTAL TEMPERATURE RATIO= 1.06377
STAGE ADIABATIC EFFICIENCY= .90463

STAGE FLOW COEFFICIENT= .512
AXIAL VELOCITY= 493.84
ROTOR SPEED= 964.04

STAGE TOTAL PRESSURE RATIO(ACTUAL)= 1.21895
STAGE TOTAL PRESSURE RATIO(IDEAL)= 1.24345
LOSS FACTOR IN ROTOR= .97403
LOSS FACTOR IN STATOR= .99138

	ROTOR INLET	*ROTOR OUTLET*	*STATOR OUTLET*
TOTAL PRESSURE	5565.72	6843.38	6784.36
STATIC PRESSURE	4921.56	5436.20	5876.36
TOTAL TEMPERATURE(GAS)	699.0183	743.5938	743.5938
STATIC TEMPERATURE(GAS)	675.0454	696.5955	713.9007
STATIC DENSITY(GAS)	.1367	.1463	.1543
STATIC DENSITY(MIXTURE)	.1367	.1463	.1543
AXIAL VELOCITY	493.8405	505.0266	478.8044
ABSOLUTE VELOCITY	538.5989	754.2557	599.5224
RELATIVE VELOCITY	780.2545	557.2913	
BLADE SPEED	819.0509	795.8534	.5000
TANG. COMP. OF ABS. VEL.	214.9659	560.2230	
TANG. COMP. OF REL. VEL.	604.0850	235.6304	
ACOUSTIC SPEED	1271.8989	1307.3852	1307.9918
ABSOLUTE MACH NUMBER	.4235	.5838	.4584
RELATIVE MACH NUMBER	.6135	.4313	
FLOW COEFFICIENT	.5123	.5239	.4994
FLOW AREA	.0051	.0047	.0047
ABSOLUTE FLOW ANGLE	23.5232	47.9662	37.0059
RELATIVE FLOW ANGLE	50.7339	25.0124	
INCIDENCE	5.6639	-.7438	
DEVIATION		10.5824	7.7259

******************* INITIAL FLOW COEFFICIENT= .50000 (ISTAGE= 6) *******************

STAGE PERFORMANCE AFTER INTER-STAGE ADJUSTMENT(JPERFM=2)

STAGE TOTAL PRESSURE RATIO= 1.21895
STAGE TOTAL TEMPERATURE RATIO= 1.06377
STAGE ADIABATIC EFFICIENCY= .90463

	STAGE INLET	**STAGE OUTLET** (BEFORE INTER-STAGE ADJUSTMENT)	**STAGE OUTLET** (AFTER INTER-STAGE ADJUSTMENT)
XV=	.00000	.00000	.00000
XW=	0	0	0
XWW=	0	0	0
XWT=	0	0	0
XAIR=	1.00000	1.00000	1.00000
XMETAN=	0	0	0
XGAS	1.00000	1.00000	1.00000
WMASS=	0	0	0
WWMASS=	0	0	0
WTMASS=	0	0	0
AMASS=	.34491	.34491	.34491
CHMASS=	0	0	0
VMASS=	.00000	.00000	.00000
GMASS=	.34491	.34491	.34491
TMASS=	.34491	.34491	.34491
WS=	.00000	.00000	.00000
RHOA=	.14924	.14623	.15426
RHOM=	.06904	.14623	.15426
RHOG=	.13665	.14623	.15426
TG=	699.01831	743.59381	743.59381
TW=	513.70000	513.70000	513.70000
TWW=	513.70000	0	513.70000
P=	5565.71763	6843.37717	6784.35886
TB=	725.30379	0	737.46504
TDEW=	270.78298	272.44415	272.44415

```
********** OVERALL PERFORMANCE *********

INITIAL FLOW COEFFICIENT= .50000

CORRECTED SPEED=51120.0     1.000 FRACTION OF DEIGN CORRECTED SPEED

INITIAL WATER CONTENT(SMALL DROPLET)=    0
INITIAL WATER CONTENT(LARGE DROPLET)=    0
INITIAL WATER CONTENT(TOTAL)=    0
INITIAL RELATIVE HUMIDITY=   .0 PER CENT
INITIAL METHANE CONTENT=    0

COMPRESSOR INLET TOTAL TEMPERATURE=  518.70

COMPRESSOR INLET TOTAL PRESSURE=   2116.80

CORRECTED MASS FLOW RATE OF MIXTURE=  .345( 2.910)

CORRECTED MASS FLOW RATE OF GAS PHASE   .345( 2.910)

OVERALL TOTAL PRESSURE RATIO=3.2050

OVERALL TOTAL TEMPERATURE RATIO=1.4336

OVERALL ADIABATIC EFFICIENCY= .9057

OVERALL TEMPERATURE RISE OF GAS PHASE= 224.894
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AD-A114 850 PURDUE UNIV LAFAYETTE IN SCHOOL OF MECHANICAL ENGINEERING F/G 21/5
EFFECT OF WATER ON AXIAL FLOW COMPRESSORS. PART I. ANALYSIS AND--ETC(U)
JUN 81 T TSUCHIYA, S N MURTHY F33615-78-C-2401
UNCLASSIFIED AFWAL-TR-80-2090-PT-1 NL

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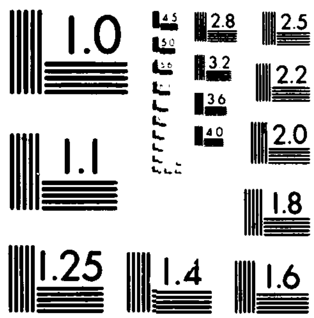

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

A.5.2 Test Case Part II

****************************** INPUT DATA ************************************

NS(NUMBER OF STAGE)= 6
UNIT=ENGLISH UNIT
IPERFM=2
PERFORMANCE AT MEAN

	1	2	3	4	5	6	IGV
RRHUB(I)	.770	1.035	1.232	1.378	1.489	1.572	
RC(I)	.605	.554	.534	.510	.483	.456	
RBLADE(I)	16.00	20.00	20.00	25.00	28.00	32.00	
STAGER(I)	34.25	29.96	27.37	28.30	29.17	29.75	
STAGES(I)	23.67	25.62	26.94	28.41	29.82	38.99	
SRHUB(I)	.923	1.145	1.311	1.445	1.538	1.580	.774
SC(I)	.442	.412	.412	.412	.412	.412	
SBLADE(I)	14.00	26.00	28.00	32.00	36.00	30.00	
SIGUMR(I)	1.052	1.120	1.037	1.182	1.211	1.283	
SIGUMS(I)	.640	1.061	1.093	1.199	1.311	1.087	
GAPR(I)	.125	.125	.125	.125	.125	.125	
GAPS(I)	.125	.125	.125	.125	.125	.125	
RRTIP(I)	2.16	2.16	2.16	2.16	2.16	2.16	
SRTIP(I)	2.16	2.16	2.16	2.16	2.16	2.16	2.16
RT(I)	2.149	2.151	2.148	2.149	2.149	2.147	
RM(I)	1.426	1.575	1.642	1.722	1.789	1.836	
RH(I)	.781	1.056	1.252	1.411	1.533	1.621	
ST(I)	2.147	2.138	2.127	2.123	2.118	2.100	
SM(I)	1.502	1.573	1.637	1.712	1.766	1.784	
SH(I)	.934	1.152	1.318	1.453	1.548	1.592	
BLOCK(I)	.983	.976	.967	.949	.923	.902	
BLOCKS(I)	.978	.966	.945	.928	.908	.863	
BET1MR(I)	42.72	42.74	41.62	42.85	44.00	45.07	
BET2MR(I)	25.79	17.17	13.12	13.76	14.33	14.43	
BET1MS(I)	35.15	40.11	43.36	45.00	46.31	48.71	0
BET2MS(I)	12.19	11.13	10.51	11.81	13.32	29.28	21.99
PR12D(I)	1.154	1.165	1.221	1.237	1.230	1.215	
PR13D(I)	1.152	1.159	1.213	1.228	1.221	1.208	
ETARD(I)	.966	.966	.968	.965	.962	.954	

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***************************** INPUT DATA *****************************
FNF(FRACTION OF DESIGN CORRECTED SPEED)=1.000

XDIN(INITIAL WATER CONTENT OF SMALL DROPLET)= .040
XDDIN(INITIAL WATER CONTENT OF LARGE DROPLET)=    0
RHUMID(INITIAL RELATIVE HUMIDITY)=   .00 PER CENT
XCH4(INITIAL METHANE CONTENT)=    0

TOG(COMPRESSOR INLET TOTAL TEMPRATURE OF GAS)= 518.70
TOW(COMPRESSOR INLET TEMPERATURE OF DROPLRET)= 513.70
PO(COMPRESSOR INLET TOTAL PRESSURE)=   2116.80

DIN(INITIIL DROPLET DIAMETER OF SMALL DROPLET)=  20.0
DDIN(INITIAL DROPLET DIAMETER OF LARGE DROPLET)= 600.0

FND(DESIGN ROTATIONAL SPEED)=51120.0

DSMASS(DESIGN MASS FLOW RATE)=     .3755

COMPRESSOR INLET TATAL TEMPERATURE(GAS PHASE) 518.70

COMPRESSOR INLET TOTAL PRESSURE=   2116.80

PREB(PERCENT OF WATER THAT REBOUND AFTER IMPINGE   MENT)= 50.0 PERCENT

ROTOR SPEED=51120.0 RPM

CORRECTED ROTOR SPEED= 51120.0 RPM(  100.0PER CENT OF DESIGN CORRECTED SPEED)
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*************** DESIGN POINT INFORMATION ************ ***

***** COMPRESSOR INLET *****

TOTAL TEMPERATURE AT COMPRESSOR INLET= 518.70000
TOTAL PRESSURE AT COMPRESSOR INLET=   2116.80
STATIC TEMPERATURE AT COMPRESSOR INLET= 496.28109
STATIC PRESSURE AT COMPRESSOR INLET=   1813.73
STATIC DENSITY AT COMPRESSOR INLET=    .06850

ACOUSTIC SPEED AT COMPRESSOR INLET=1092.25914
AXIAL VELOCITY AT COMPRESSOR INLET= 518.81873
MACH NUMBER AT COMPRESSOR INLET=    .47500
STREAMTUBE AREA AT COMPRESSOR INLET=    .01057
FLOW COEFFICIENT AT COMPRESSOR INLET=    .53817
```

*************** DESIGN POINT INFORMATION ************ ***

***** STAGE= 1 *****

	TOTAL TEMP	TOTAL PRESSURE	STATIC TEMP	STATIC PRESSURE	STATIC DENSITY
ROTOR INLET	518.700	2116.800	492.637	1767.579	.067
ROTOR OUTLET	541.148	2442.787	508.269	1961.576	.072

	AXIAL VELOCITY	ABSOLUTE VELOCITY	RELATIVE VELOCITY	TAN COMP OF ABS VEL	TAN COMP OF REL VEL
ROTOR INLET	538.76531	559.39838	725.32398	150.52734	485.62003
ROTOR OUTLET	525.97105	628.55682	618.75550	344.14838	325.90306

	ROTOR SPEED	ABS MACH NUMBER	REL MACH NUMBER	REL TOTAL TEMP	REL TOTAL PRESSURE
ROTOR INLET	636.147	.514	.667	536.454	2381.210
ROTOR OUTLET	670.051	.569	.560	540.141	5091.790

	ABS FLOW ANGLE	REL FLOW ANGLE	STREAMTUBE AREA	RADIUS	FLOW COEFFICIENT
ROTOR INLET	15.61000	42.03015	.01036	1.42600	.55886
ROTOR OUTLET	33.19714	31.78325	.00987	1.50200	.54559

STAGE TOTAL PRESSURE RATIO AT DESIGN POINT= 1.15200
STAGE ADIABATIC EFFICIENCY AT DESIGN POINT= .95383
ROTOR TOTAL PRESSURE RATIO AT DESIGN POINT= 1.15400
ROTOR ADIABATIC EFFICIENCY AT DESIGN POINT= .96600
ROTOR TOTAL TEMPERATURE RATIO AT DESIGN POINT= 1.04328

*************** DESIGN POINT INFORMATION *********** ***

***** STAGE= 2 *****

	TOTAL TEMP	TOTAL PRESSURE	STATIC TEMP	STATIC PRESSURE	STATIC DENSITY
ROTOR INLET	541.148	2438.554	511.984	2008.852	.074
ROTOR OUTLET	566.141	2840.915	522.316	2142.394	.077

	AXIAL VELOCITY	ABSOLUTE VELOCITY	RELATIVE VELOCITY	TAN COMP OF ABS VEL	TAN COMP OF REL VEL
ROTOR INLET	549.21299	591.88727	730.68951	220.67086	481.94632
ROTOR OUTLET	581.16447	725.94045	639.44211	435.01464	266.71034

	ROTOR SPEED	ABS MACH NUMBER	REL MACH NUMBER	REL TOTAL TEMP	REL TOTAL PRESSURE
ROTOR INLET	702.617	.534	.659	556.431	2688.136
ROTOR OUTLET	701.725	.648	.571	556.331	5751.007

	ABS FLOW ANGLE	REL FLOW ANGLE	STREAMTUBE AREA	RADIUS	FLOW COEFFICIENT
ROTOR INLET	21.89000	41.26765	.00930	1.57500	.56970
ROTOR OUTLET	36.81569	24.65154	.00841	1.57300	.60285

STAGE TOTAL PRESSURE RATIO AT DESIGN POINT= 1.15900
STAGE ADIABATIC EFFICIENCY AT DESIGN POINT= .93231
ROTOR TOTAL PRESSURE RATIO AT DESIGN POINT= 1.16500
ROTOR ADIABATIC EFFICIENCY AT DESIGN POINT= .96600
ROTOR TOTAL TEMPERATURE RATIO AT DESIGN POINT= 1.04618

*************** DESIGN POINT INFORMATION *********** ***

***** STAGE= 3 *****

	TOTAL TEMP	TOTAL PRESSURE	STATIC TEMP	STATIC PRESSURE	STATIC DENSITY
ROTOR INLET	566.141	2826.284	535.362	2323.868	.081
ROTOR OUTLET	600.462	3450.892	549.786	2533.049	.086

	AXIAL VELOCITY	ABSOLUTE VELOCITY	RELATIVE VELOCITY	TAN COMP OF ABS VEL	TAN COMP OF REL VEL
ROTOR INLET	574.81563	608.26663	784.29006	198.93541	533.57089
ROTOR OUTLET	614.43880	781.11343	662.59507	482.28950	247.98627

	ROTOR SPEED	ABS MACH NUMBER	REL MACH NUMBER	REL TOTAL TEMP	REL TOTAL PRESSURE
ROTOR INLET	732.506	.536	.692	586.533	3199.070
ROTOR OUTLET	730.276	.680	.577	586.263	6929.751

	ABS FLOW ANGLE	REL FLOW ANGLE	STREAMTUBE AREA	RADIUS	FLOW COEFFICIENT
ROTOR INLET	19.09000	42.86892	.00803	1.64200	.59626
ROTOR OUTLET	38.12932	21.97890	.00708	1.63700	.63736

STAGE TOTAL PRESSURE RATIO AT DESIGN POINT= 1.21300
STAGE ADIABATIC EFFICIENCY AT DESIGN POINT= .93464
ROTOR TOTAL PRESSURE RATIO AT DESIGN POINT= 1.22100
ROTOR ADIABATIC EFFICIENCY AT DESIGN POINT= .96800
ROTOR TOTAL TEMPERATURE RATIO AT DESIGN POINT= 1.06062

************** DESIGN POINT INFORMATION ************ ***

***** STAGE= 4 *****

	TOTAL TEMP	TOTAL PRESSURE	STATIC TEMP	STATIC PRESSURE	STATIC DENSITY
ROTOR INLET	600.462	3428.282	569.069	2839.988	.094
ROTOR OUTLET	639.381	4240.785	585.841	3118.959	.100

	AXIAL VELOCITY	ABSOLUTE VELOCITY	RELATIVE VELOCITY	TAN COMP OF ABS VEL	TAN COMP OF REL VEL
ROTOR INLET	580.04590	614.69778	809.54747	203.47020	564.72459
ROTOR OUTLET	619.63965	803.61317	668.93304	511.70446	252.02926

	ROTOR SPEED	ABS MACH NUMBER	REL MACH NUMBER	REL TOTAL TEMP	REL TOTAL PRESSURE
ROTOR INLET	768.195	.526	.692	623.519	3912.431
ROTOR OUTLET	763.734	.678	.564	622.951	8231.914

	ABS FLOW ANGLE	REL FLOW ANGLE	STREAMTUBE AREA	RADIUS	FLOW COEFFICIENT
ROTOR INLET	19.33000	44.23321	.00692	1.72200	.60169
ROTOR OUTLET	39.55025	22.13332	.00607	1.71200	.64276

STAGE TOTAL PRESSURE RATIO AT DESIGN POINT= 1.22800
STAGE ADIABATIC EFFICIENCY AT DESIGN POINT= .93002
ROTOR TOTAL PRESSURE RATIO AT DESIGN POINT= 1.23700
ROTOR ADIABATIC EFFICIENCY AT DESIGN POINT= .96500
ROTOR TOTAL TEMPERATURE RATIO AT DESIGN POINT= 1.06481

**************** DESIGN POINT INFORMATION ************ ***

***** STAGE= 5 *****

	TOTAL TEMP	TOTAL PRESSURE	STATIC TEMP	STATIC PRESSURE	STATIC DENSITY
ROTOR INLET	639.381	4209.930	606.962	3506.755	.108
ROTOR OUTLET	679.732	5178.214	625.197	3857.244	.116

	AXIAL VELOCITY	ABSOLUTE VELOCITY	RELATIVE VELOCITY	TAN COMP OF ABS VEL	TAN COMP OF REL VEL
ROTOR INLET	586.84149	625.22167	826.78513	215.68308	582.40082
ROTOR OUTLET	617.08868	811.98444	669.65381	527.75042	260.07304

	ROTOR SPEED	ABS MACH NUMBER	REL MACH NUMBER	REL TOTAL TEMP	REL TOTAL PRESSURE
ROTOR INLET	798.084	.518	.685	663.653	4798.526
ROTOR OUTLET	787.823	.663	.547	662.302	9691.778

	ABS FLOW ANGLE	REL FLOW ANGLE	STREAMTUBE AREA	RADIUS	FLOW COEFFICIENT
ROTOR INLET	20.18000	44.78240	.00591	1.78900	.60873
ROTOR OUTLET	40.53794	22.85308	.00526	1.76600	.64011

STAGE TOTAL PRESSURE RATIO AT DESIGN POINT= 1.22100
STAGE ADIABATIC EFFICIENCY AT DESIGN POINT= .92580
ROTOR TOTAL PRESSURE RATIO AT DESIGN POINT= 1.23000
ROTOR ADIABATIC EFFICIENCY AT DESIGN POINT= .96200
ROTOR TOTAL TEMPERATURE RATIO AT DESIGN POINT= 1.06311

*************** DESIGN POINT INFORMATION ************ ***

***** STAGE= 6 *****

	TOTAL TEMP	TOTAL PRESSURE	STATIC TEMP	STATIC PRESSURE	STATIC DENSITY
ROTOR INLET	679.732	5140.325	646.933	4318.954	.125
ROTOR OUTLET	720.259	6245.495	665.989	4736.291	.133

	AXIAL VELOCITY	ABSOLUTE VELOCITY	RELATIVE VELOCITY	TAN COMP OF ABS VEL	TAN COMP OF REL VEL
ROTOR INLET	587.19574	629.60666	833.74045	227.16890	591.88199
ROTOR OUTLET	603.39773	811.09676	654.61329	542.02320	253.83017

	ROTOR SPEED	ABS MACH NUMBER	REL MACH NUMBER	REL TOTAL TEMP	REL TOTAL PRESSURE
ROTOR INLET	819.051	.506	.669	704.449	5829.034
ROTOR OUTLET	795.853	.642	.518	701.350	10970.182

	ABS FLOW ANGLE	REL FLOW ANGLE	STREAMTUBE AREA	RADIUS	FLOW COEFFICIENT
ROTOR INLET	21.15000	45.22772	.00511	1.83600	.60910
ROTOR OUTLET	41.93288	22.81494	.00467	1.78400	.62591

STAGE TOTAL PRESSURE RATIO AT DESIGN POINT= 1.20800
STAGE ADIABATIC EFFICIENCY AT DESIGN POINT= .92365
ROTOR TOTAL PRESSURE RATIO AT DESIGN POINT= 1.21500
ROTOR ADIABATIC EFFICIENCY AT DESIGN POINT= .95400
ROTOR TOTAL TEMPERATURE RATIO AT DESIGN POINT= 1.05962

************** DESIGN POINT INFORMATION *********** ***

********** OVERALL PERFORMANCE AT DESIGN POINT ****   ******

COMPRESSOR INLET TOTAL TEMPERATURE= 518.70

COMPRESSOR INLET TOTAL PRESSURE= 2116.80

CORRECTED MASS FLOW RATE= 3.168

OVERALL TOTAL PRESSURE RATIO=2.9334

OVERALL TOTAL TEMPERATURE RATIO=1.3886

OVERALL ADIABATIC EFFICIENCY= .9223

OVERALL TEMPERATURE RISE= 201.559

	1	2	3	4	5	6	IGV
BET1SR(I)	42.03	41.27	42.87	44.23	44.78	45.23	
BET2SR(I)	31.78	24.65	21.98	22.13	22.85	22.81	
AINCSR(I)	-.69	-1.47	1.25	1.38	.78	.16	
ADEVSR(I)	5.99	7.48	8.86	8.37	8.52	8.38	
BET1SS(I)	33.20	36.82	38.13	39.55	40.54	41.93	
BET2SS(I)	21.89	19.09	19.33	20.18	21.15	34.86	15.61
AINCSS(I)	-1.95	-3.29	-5.23	-5.45	-5.77	-6.78	
ADEVSS(I)	9.70	7.96	8.82	8.37	7.83	5.58	
TD(I)	518.7	541.1	566.1	600.5	639.4	679.7	
OMEGS(I)	.009	.021	.025	.028	.029	.024	
OMEGR(I)	.020	.021	.024	.028	.030	.036	

******************** INITIAL FLOW COEFFICIENT= .50000 (STAGE= 1) ************

STAGE TOTAL PRESSURE RATIO= 1.17523
STAGE TOTAL TEMPERATURE RATIO= 1.05076
STAGE ADIABATIC EFFICIENCY= .93056

STAGE FLOW COEFFICIENT= .500
AXIAL VELOCITY= 482.13
ROTOR SPEED= 964.04

STAGE TOTAL PRESSURE RATIO(ACTUAL)= 1.17523
STAGE TOTAL PRESSURE RATIO(IDEAL)= 1.18907
LOSS FACTOR IN ROTOR= 1.01550
LOSS FACTOR IN STATOR= .99678

	ROTOR INLET	*ROTOR OUTLET*	*STATOR OUTLET*
TOTAL PRESSURE	2116.80	2495.77	2487.73
STATIC PRESSURE	1821.98	2038.83	2123.98
TOTAL TEMPERATURE(GAS)	518.7000	545.0303	545.0303
STATIC TEMPERATURE(GAS)	496.9259	515.5746	521.8709
STATIC DENSITY(GAS)	.0687	.0741	.0763
STATIC DENSITY(MIXTURE)	.0716	.0772	.0795
AXIAL VELOCITY	482.1269	469.4052	484.1839
ABSOLUTE VELOCITY	500.9958	594.7932	527.4057
RELATIVE VELOCITY	694.5454	559.6606	
BLADE SPEED	636.1474	670.0514	702.6172
TANG. COMP. OF ABS. VEL.	136.2004	365.2913	
TANG. COMP. OF REL. VEL.	499.9470	304.7602	
ACOUSTIC SPEED	1070.9353	1097.8191	1097.4899
ABSOLUTE MACH NUMBER	.4678	.5453	.4806
RELATIVE MACH NUMBER	.6485	.5131	
FLOW COEFFICIENT	.5001	.4869	.5022
FLOW AREA	.0104	.0099	.0093
ABSOLUTE FLOW ANGLE	15.7749	37.8901	23.3618
RELATIVE FLOW ANGLE	46.0395	32.9935	
INCIDENCE	3.3195	2.7401	
DEVIATION		7.2035	11.1718

******************** INITIAL FLOW COEFFICIENT= .50000 (ISTAGE= 1) ********************

STAGE PERFORMANCE AFTER INTER-STAGE ADJUSTMENT(JPERFM=2)

STAGE TOTAL PRESSURE RATIO= 1.17523
STAGE TOTAL TEMPERATURE RATIO= 1.05076
STAGE ADIABATIC EFFICIENCY= .93059

	STAGE INLET	**STAGE OUTLET** (BEFORE INTER-STAGE ADJUSTMENT)	**STAGE OUTLET** (AFTER INTER-STAGE ADJUSTMENT)
XV=	.00000	.00000	.00003
XW=	.04000	.04000	.03997
XWW=	0	0	0
XWT=	.04000	.04000	.03997
XAIR=	.96000	.96000	.96000
XMETAN=	0	0	0
XGAS	.96000	.96000	.96003
WMASS=	.01431	.01431	.01430
WWMASS=	0	0	0
WTMASS=	.01431	.01431	.01430
AMASS=	.34340	.34340	.34340
CHMASS=	0	0	0
VMASS=	.00000	.00000	.00001
GMASS=	.34340	.34340	.34341
TMASS=	.35771	.35771	.35771
WS=	.00000	.00000	.00004
RHOA=	.07649	.07432	.06829
RHOM=	.07160	.07741	.07961
RHOG=	.06872	.07432	.07643
TG=	518.70000	545.03032	545.02935
TW=	513.70000	519.12521	519.13056
TWW=	513.70000	0	513.70000
P=	2116.80000	2495.76975	2487.72825
TB=	671.40656	0	679.39541
TDEW=	271.99506	273.32309	395.40315

******************** INITIAL FLOW COEFFICIENT= .50000 (STAGE= 2) ******************

STAGE TOTAL PRESSURE RATIO= 1.17581
STAGE TOTAL TEMPERATURE RATIO= 1.05225
STAGE ADIABATIC EFFICIENCY= .90620

STAGE FLOW COEFFICIENT= .501
AXIAL VELOCITY= 483.25
ROTOR SPEED= 964.04

STAGE TOTAL PRESSURE RATIO(ACTUAL)= 1.17581
STAGE TOTAL PRESSURE RATIO(IDEAL)= 1.19510
LOSS FACTOR IN ROTOR= .99123
LOSS FACTOR IN STATOR= .99193

	ROTOR INLET	*ROTOR OUTLET*	*STATOR OUTLET*
TOTAL PRESSURE	2487.73	2948.91	2925.11
STATIC PRESSURE	2124.70	2286.71	2506.57
TOTAL TEMPERATURE(GAS)	545.0293	573.5085	573.5085
STATIC TEMPERATURE(GAS)	521.0067	534.8122	549.7050
STATIC DENSITY(GAS)	.0764	.0801	.0855
STATIC DENSITY(MIXTURE)	.0796	.0835	.0890
AXIAL VELOCITY	483.2456	509.8557	500.4203
ABSOLUTE VELOCITY	526.4003	681.9413	534.8508
RELATIVE VELOCITY	690.9735	567.3462	
BLADE SPEED	702.6172	701.7250	732.5063
TANG. COMP. OF ABS. VEL.	208.7366	452.8698	
TANG. COMP. OF REL. VEL.	493.8806	248.8552	
ACOUSTIC SPEED	1096.4867	1126.0773	1126.2833
ABSOLUTE MACH NUMBER	.4801	.6139	.4749
RELATIVE MACH NUMBER	.6302	.5107	
FLOW COEFFICIENT	.5013	.5289	.5191
FLOW AREA	.0093	.0084	.0080
ABSOLUTE FLOW ANGLE	23.3618	41.6125	20.6723
RELATIVE FLOW ANGLE	45.6236	26.0165	
INCIDENCE	2.8836	1.5025	
DEVIATION		8.8465	9.5423

******************** INITIAL FLOW COEFFICIENT= .50000 (ISTAGE= 2) ********************

STAGE PERFORMANCE AFTER INTER-STAGE ADJUSTMENT(JPERFM=2)

STAGE TOTAL PRESSURE RATIO= 1.17581
STAGE TOTAL TEMPERATURE RATIO= 1.05225
STAGE ADIABATIC EFFICIENCY= .90625

	STAGE INLET	**STAGE OUTLET** (BEFORE INTER-STAGE ADJUST-MENT)	**STAGE OUTLET** (AFTER INTER-STAGE ADJUST-MENT)
XV=	.00003	.00003	.00011
XW=	.03997	.03997	.03989
XWW=	0	0	0
XWT=	.03997	.03997	.03989
XAIR=	.96000	.96000	.96000
XMETAN=	0	0	0
XGAS	.96003	.96003	.96011
WMASS=	.01430	.01430	.01427
WWMASS=	0	0	0
WTMASS=	.01430	.01430	.01427
AMASS=	.34340	.34340	.34340
CHMASS=	0	0	0
VMASS=	.00001	.00001	.00004
GMASS=	.34341	.34341	.34344
TMASS=	.35771	.35771	.35771
WS=	.00004	.00004	.00011
RHOA=	.08555	.08043	.07670
RHOM=	.07160	.08377	.08918
RHOG=	.07643	.08043	.08563
TG=	545.02935	573.50850	573.50651
TW=	519.13056	524.60917	524.62018
TWW=	513.70000	0	513.70000
P=	2487.72825	2948.91283	2925.10631
TB=	679.39541	0	687.60211
TDEW=	395.40315	398.30836	418.76408

******************** INITIAL FLOW COEFFICIENT= .50000 (STAGE= 3) ***********

STAGE TOTAL PRESSURE RATIO= 1.22461
STAGE TOTAL TEMPERATURE RATIO= 1.06555
STAGE ADIABATIC EFFICIENCY= .90795

STAGE FLOW COEFFICIENT= .518
AXIAL VELOCITY= 499.52
ROTOR SPEED= 964.04

STAGE TOTAL PRESSURE RATIO(ACTUAL)= 1.22461
STAGE TOTAL PRESSURE RATIO(IDEAL)= 1.24902
LOSS FACTOR IN ROTOR= .98903
LOSS FACTOR IN STATOR= .98975

	ROTOR INLET	*ROTOR OUTLET*	*STATOR OUTLET*
TOTAL PRESSURE	2925.11	3619.23	3582.11
STATIC PRESSURE	2507.36	2750.82	3093.78
TOTAL TEMPERATURE(GAS)	573.5065	611.0987	611.0987
STATIC TEMPERATURE(GAS)	548.8198	566.7669	587.0191
STATIC DENSITY(GAS)	.0856	.0910	.0988
STATIC DENSITY(MIXTURE)	.0892	.0947	.1029
AXIAL VELOCITY	499.5199	533.4818	502.3745
ABSOLUTE VELOCITY	533.8950	730.2472	538.1919
RELATIVE VELOCITY	738.5713	581.5931	
BLADE SPEED	732.5063	730.2758	768.1948
TANG. COMP. OF ABS. VEL.	188.4774	498.6562	
TANG. COMP. OF REL. VEL.	544.0289	231.6196	
ACOUSTIC SPEED	1125.2535	1163.7666	1163.7592
ABSOLUTE MACH NUMBER	.4745	.6386	.4625
RELATIVE MACH NUMBER	.6564	.5086	
FLOW COEFFICIENT	.5182	.5534	.5211
FLOW AREA	.0080	.0071	.0069
ABSOLUTE FLOW ANGLE	20.6723	43.0675	21.0210
RELATIVE FLOW ANGLE	47.4423	23.4688	
INCIDENCE	5.8223	-.2925	
DEVIATION		10.3488	10.5110

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*******************   INITIAL FLOW COEFFICIENT=  .50000 (ISTAGE=  3 )  *******************

STAGE PERFORMANCE AFTER INTER-STAGE ADJUSTMENT(JPERFM=2)

STAGE TOTAL PRESSURE RATIO=      1.22461
STAGE TOTAL TEMPERATURE RATIO=     1.06554
STAGE ADIABATIC EFFICIENCY=      .90801

        **STAGE INLET**      **STAGE OUTLET**      **STAGE OUTLET**
                              (BEFORE INTER-        (AFTER INTER-
                              STAGE ADJUST-         STAGE ADJUST-
                              MENT)                 MENT)
XV=            .00011          .00011                .00023
XW=            .03989          .03989                .03977
XWW=              0               0                     0
XWT=           .03989          .03989                .03977
XAIR=          .96000          .96000                .96000
XMETAN=           0               0                     0
XGAS           .96011          .96011                .96023
WMASS=         .01427          .01427                .01422
WWMASS=           0               0                     0
WTMASS=        .01427          .01427                .01422
AMASS=         .34340          .34340                .34340
CHMASS=           0               0                     0
VMASS=         .00004          .00004                .00008
GMASS=         .34344          .34344                .34348
TMASS=         .35771          .35771                .35771
WS=            .00011          .00011                .00024
RHOA=          .09560          .09133                .08912
RHOM=          .07160          .09511                .10303
RHOG=          .08563          .09132                .09894
TG=         573.50651       611.09874             611.09555
TW=         524.62018       531.47995             531.49766
TWW=        513.70000           0                 513.70000
P=         2925.10631      3619.22732            3582.11448
TB=         687.60211           0                 698.15264
TDEW=       418.76408       422.85381             437.94261
```

******************** INITIAL FLOW COEFFICIENT= .50000 (STAGE= 4) ********************

STAGE TOTAL PRESSURE RATIO= 1.23734
STAGE TOTAL TEMPERATURE RATIO= 1.06937
STAGE ADIABATIC EFFICIENCY= .90133

STAGE FLOW COEFFICIENT= .520
AXIAL VELOCITY= 501.59
ROTOR SPEED= 964.04

STAGE TOTAL PRESSURE RATIO(ACTUAL)= 1.23734
STAGE TOTAL PRESSURE RATIO(IDEAL)= 1.26524
LOSS FACTOR IN ROTOR= .98600
LOSS FACTOR IN STATOR= .98874

	ROTOR INLET	*ROTOR OUTLET*	*STATOR OUTLET*
TOTAL PRESSURE	3582.11	4482.78	4432.28
STATIC PRESSURE	3094.58	3413.81	3849.29
TOTAL TEMPERATURE(GAS)	611.0955	653.4876	653.4876
STATIC TEMPERATURE(GAS)	586.1317	606.4676	628.7251
STATIC DENSITY(GAS)	.0989	.1055	.1147
STATIC DENSITY(MIXTURE)	.1030	.1099	.1195
AXIAL VELOCITY	501.5901	536.1439	506.6302
ABSOLUTE VELOCITY	537.3515	752.6615	546.2044
RELATIVE VELOCITY	763.3644	585.5788	
BLADE SPEED	768.1948	763.7337	798.0839
TANG. COMP. OF ABS. VEL.	192.7537	528.2509	
TANG. COMP. OF REL. VEL.	575.4411	235.4829	
ACOUSTIC SPEED	1162.6546	1204.1692	1204.1634
ABSOLUTE MACH NUMBER	.4622	.6364	.4536
RELATIVE MACH NUMBER	.6566	.4951	
FLOW COEFFICIENT	.5203	.5561	.5255
FLOW AREA	.0069	.0061	.0059
ABSOLUTE FLOW ANGLE	21.0210	44.5751	21.9444
RELATIVE FLOW ANGLE	48.9226	23.7118	
INCIDENCE	6.0726	-.4249	
DEVIATION		9.9518	10.1344

******************** INITIAL FLOW COEFFICIENT= .50000 (ISTAGE= 4) ********************

STAGE PERFORMANCE AFTER INTER-STAGE ADJUSTMENT(JPERFM=2)

STAGE TOTAL PRESSURE RATIO= 1.23734
STAGE TOTAL TEMPERATURE RATIO= 1.06936
STAGE ADIABATIC EFFICIENCY= .90140

	STAGE INLET	**STAGE OUTLET** (BEFORE INTER-STAGE ADJUSTMENT)	**STAGE OUTLET** (AFTER INTER-STAGE ADJUSTMENT)
XV=	.00023	.00023	.00043
XW=	.03977	.03977	.03957
XWW=	0	0	0
XWT=	.03977	.03977	.03957
XAIR=	.96000	.96000	.96000
XMETAN=	0	0	0
XGAS	.96023	.96023	.96043
WMASS=	.01422	.01422	.01416
WWMASS=	0	0	0
WTMASS=	.01422	.01422	.01416
AMASS=	.34340	.34340	.34340
CHMASS=	0	0	0
VMASS=	.00008	.00008	.00015
GMASS=	.34348	.34348	.34355
TMASS=	.35771	.35771	.35771
WS=	.00024	.00024	.00044
RHOA=	.10987	.10590	.10390
RHOM=	.07160	.11027	.11964
RHOG=	.09894	.10589	.11491
TG=	611.09555	653.48757	653.48292
TW=	531.49766	538.61927	538.64525
TWW=	513.70000	0	513.70000
P=	3582.11448	4482.77596	4432.28162
TB=	698.15264	0	709.59620
TDEW=	437.94261	442.65883	455.51405

******************** INITIAL FLOW COEFFICIENT= .50000 (STAGE= 5) ******************

STAGE TOTAL PRESSURE RATIO= 1.22960
STAGE TOTAL TEMPERATURE RATIO= 1.06748
STAGE ADIABATIC EFFICIENCY= .89617

STAGE FLOW COEFFICIENT= .525
AXIAL VELOCITY= 505.96
ROTOR SPEED= 964.04

STAGE TOTAL PRESSURE RATIO(ACTUAL)= 1.22960
STAGE TOTAL PRESSURE RATIO(IDEAL)= 1.25805
LOSS FACTOR IN ROTOR= .98167
LOSS FACTOR IN STATOR= .98872

	ROTOR INLET	*ROTOR OUTLET*	*STATOR OUTLET*
TOTAL PRESSURE	4432.28	5512.15	5449.96
STATIC PRESSURE	3850.09	4245.77	4768.53
TOTAL TEMPERATURE(GAS)	653.4829	697.5827	697.5827
STATIC TEMPERATURE(GAS)	627.8227	649.5072	672.5710
STATIC DENSITY(GAS)	.1149	.1225	.1329
STATIC DENSITY(MIXTURE)	.1196	.1275	.1383
AXIAL VELOCITY	505.9606	532.9952	505.9950
ABSOLUTE VELOCITY	545.4824	761.9382	549.5787
RELATIVE VELOCITY	780.4550	585.9152	
BLADE SPEED	798.0839	787.8235	819.0509
TANG. COMP. OF ABS. VEL.	203.8501	544.4869	
TANG. COMP. OF REL. VEL.	594.2338	243.3366	
ACOUSTIC SPEED	1202.9772	1244.6349	1245.1170
ABSOLUTE MACH NUMBER	.4534	.6227	.4414
RELATIVE MACH NUMBER	.6488	.4789	
FLOW COEFFICIENT	.5248	.5529	.5249
FLOW AREA	.0059	.0053	.0051
ABSOLUTE FLOW ANGLE	21.9444	45.6111	22.9819
RELATIVE FLOW ANGLE	49.5873	24.5389	
INCIDENCE	5.5873	-.6989	
DEVIATION		10.2089	9.6619

******************** INITIAL FLOW COEFFICIENT= .50000 (ISTAGE= 5) ********************

STAGE PERFORMANCE AFTER INTER-STAGE ADJUSTMENT(JPERFM=2)

STAGE TOTAL PRESSURE RATIO= 1.22960
STAGE TOTAL TEMPERATURE RATIO= 1.06747
STAGE ADIABATIC EFFICIENCY= .89626

	STAGE INLET	**STAGE OUTLET** (BEFORE INTER-STAGE ADJUSTMENT)	**STAGE OUTLET** (AFTER INTER-STAGE ADJUSTMENT)
XV=	.00043	.00043	.00069
XW=	.03957	.03957	.03931
XWW=	0	0	0
XWT=	.03957	.03957	.03931
XAIR=	.96000	.96000	.96000
XMETAN=	0	0	0
XGAS	.96043	.96043	.96069
WMASS=	.01416	.01416	.01406
WWMASS=	0	0	0
WTMASS=	.01416	.01416	.01406
AMASS=	.34340	.34340	.34340
CHMASS=	0	0	0
VMASS=	.00015	.00015	.00025
GMASS=	.34355	.34355	.34365
TMASS=	.35771	.35771	.35771
WS=	.00044	.00044	.00072
RHOA=	.12713	.12295	.12090
RHOM=	.07160	.12797	.13846
RHOG=	.11491	.12291	.13303
TG=	653.48292	697.58272	697.57655
TW=	538.64525	545.85731	545.89207
TWW=	513.70000	0	513.70000
P=	4432.28162	5512.15360	5449.95512
TB=	709.59620	0	724.03629
TDEW=	455.51405	452.07093	463.59244

******************** INITIAL FLOW COEFFICIENT= .50000 (STAGE= 6) ********************

STAGE TOTAL PRESSURE RATIO= 1.21465
STAGE TOTAL TEMPERATURE RATIO= 1.06335
STAGE ADIABATIC EFFICIENCY= .89377

STAGE FLOW COEFFICIENT= .524
AXIAL VELOCITY= 505.48
ROTOR SPEED= 964.04

STAGE TOTAL PRESSURE RATIO(ACTUAL)= 1.21465
STAGE TOTAL PRESSURE RATIO(IDEAL)= 1.24176
LOSS FACTOR IN ROTOR= .97277
LOSS FACTOR IN STATOR= .99051

	ROTOR INLET	*ROTOR OUTLET*	*STATOR OUTLET*
TOTAL PRESSURE	5449.96	6683.24	6619.79
STATIC PRESSURE	4769.14	5228.99	5656.21
TOTAL TEMPERATURE(GAS)	697.5765	741.7702	741.7702
STATIC TEMPERATURE(GAS)	671.6630	693.7308	710.6187
STATIC DENSITY(GAS)	.1330	.1412	.1491
STATIC DENSITY(MIXTURE)	.1385	.1470	.1552
AXIAL VELOCITY	505.4755	521.2389	493.6021
ABSOLUTE VELOCITY	549.0550	762.7687	614.2333
RELATIVE VELOCITY	788.1246	573.4053	
BLADE SPEED	819.0509	795.8534	.5000
TANG. COMP. OF ABS. VEL.	214.3734	556.8897	
TANG. COMP. OF REL. VEL.	604.6775	238.9637	
ACOUSTIC SPEED	1243.8832	1279.4619	1279.4537
ABSOLUTE MACH NUMBER	.4414	.6034	.4801
RELATIVE MACH NUMBER	.6336	.4536	
FLOW COEFFICIENT	.5243	.5407	.5149
FLOW AREA	.0051	.0047	.0047
ABSOLUTE FLOW ANGLE	22.9819	46.8939	36.5240
RELATIVE FLOW ANGLE	50.1063	24.6292	
INCIDENCE	5.0363	-1.8161	
DEVIATION		10.1992	7.2440

******************* INITIAL FLOW COEFFICIENT= .50000 (ISTAGE= 6) *******************

STAGE PERFORMANCE AFTER INTER-STAGE ADJUSTMENT(JPERFM=2)

STAGE TOTAL PRESSURE RATIO= 1.21465
STAGE TOTAL TEMPERATURE RATIO= 1.06334
STAGE ADIABATIC EFFICIENCY= .89388

	STAGE INLET	**STAGE OUTLET** (BEFORE INTER-STAGE ADJUSTMENT)	**STAGE OUTLET** (AFTER INTER-STAGE ADJUSTMENT)
XV=	.00069	.00069	.00105
XW=	.03931	.03931	.03895
XWW=	0	0	0
XWT=	.03931	.03931	.03895
XAIR=	.96000	.96000	.96000
XMETAN=	0	0	0
XGAS	.96069	.96069	.96105
WMASS=	.01406	.01406	.01393
WWMASS=	0	0	0
WTMASS=	.01406	.01406	.01393
AMASS=	.34340	.34340	.34340
CHMASS=	0	0	0
VMASS=	.00025	.00025	.00038
GMASS=	.34365	.34365	.34377
TMASS=	.35771	.35771	.35771
WS=	.00072	.00072	.00110
RHOA=	.14644	.14172	.13343
RHOM=	.07160	.14744	.15538
RHOG=	.13303	.14165	.14935
TG=	697.57655	741.77019	741.76245
TW=	545.89207	552.83791	552.88194
TWW=	513.70000	0	513.70000
P=	5449.95512	6683.24452	6619.79326
TB=	724.03629	0.	735.93466
TDEW=	463.59244	468.68226	479.11464

********** OVERALL PERFORMANCE *********

INITIAL FLOW COEFFICIENT= .50000

CORRECTED SPEED=51120.0   1.000 FRACTION OF DEIGN CORRECTED SPEED

INITIAL WATER CONTENT(SMALL DROPLET)= .040
INITIAL WATER CONTENT(LARGE DROPLET)=   0
INITIAL WATER CONTENT(TOTAL)= .040
INITIAL RELATIVE HUMIDITY=   .0 PER CENT
INITIAL METHANE CONTENT=   0

COMPRESSOR INLET TOTAL TEMPERATURE= 518.70

COMPRESSOR INLET TOTAL PRESSURE=   2116.80

CORRECTED MASS FLOW RATE OF MIXTURE= .358(3.018)

CORRECTED MASS FLOW RATE OF GAS PHASE   .343(2.897)

OVERALL TOTAL PRESSURE RATIO=3.1273

OVERALL TOTAL TEMPERATURE RATIO=1.4300

OVERALL ADIABATIC EFFICIENCY= .8905

OVERALL TEMPERATURE RISE OF GAS PHASE= 223.062

A.5.3 Test Case Part III

****************************** INPUT DATA **

NS(NUMBER OF STAGE)= 6
UNIT=ENGLISH UNIT
IPERFM=2
PERFORMANCE AT MEAN

	1	2	3	4	5	6	IGV
RRHUB(I)	.770	1.035	1.232	1.378	1.489	1.572	
RC(I)	.605	.554	.534	.510	.483	.456	
RBLADE(I)	16.00	20.00	20.00	25.00	28.00	32.00	
STAGER(I)	34.25	29.96	27.37	28.30	29.17	29.75	
STAGES(I)	23.67	25.62	26.94	28.41	29.82	38.99	
SRHUB(I)	.923	1.145	1.311	1.445	1.538	1.580	.774
SC(I)	.442	.412	.412	.412	.412	.412	
SBLADE(I)	14.00	26.00	28.00	32.00	36.00	30.00	
SIGUMR(I)	1.052	1.120	1.037	1.182	1.211	1.283	
SIGUMS(I)	.640	1.061	1.093	1.199	1.311	1.087	
GAPR(I)	.125	.125	.125	.125	.125	.125	
GAPS(I)	.125	.125	.125	.125	.125	.125	
RRTIP(I)	2.16	2.16	2.16	2.16	2.16	2.16	
SRTIP(I)	2.16	2.16	2.16	2.16	2.16	2.16	2.16
RT(I)	2.149	2.151	2.148	2.149	2.149	2.147	
RM(I)	1.426	1.575	1.642	1.722	1.789	1.836	
RH(I)	.781	1.056	1.252	1.411	1.533	1.621	
ST(I)	2.147	2.138	2.127	2.123	2.118	2.100	
SM(I)	1.502	1.573	1.637	1.712	1.766	1.784	
SH(I)	.934	1.152	1.318	1.453	1.548	1.592	
BLUCK(I)	.983	.976	.967	.949	.923	.902	
BLOCKS(I)	.978	.966	.945	.928	.908	.863	
BET1MR(I)	42.72	42.74	41.62	42.85	44.00	45.07	
BET2MR(I)	25.79	17.17	13.12	13.76	14.33	14.43	
BET1MS(I)	35.15	40.11	43.36	45.00	46.31	48.71	0
BET2MS(I)	12.19	11.13	10.51	11.81	13.32	29.28	21.99
PR12D(I)	1.154	1.165	1.221	1.237	1.230	1.215	
PR13D(I)	1.152	1.159	1.213	1.228	1.221	1.208	
ETARD(I)	.966	.966	.968	.965	.962	.954	

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******************************* INPUT DATA ******************************
FNF(FRACTION OF DESIGN CORRECTED SPEED)=1.000

XDIN(INITIAL WATER CONTENT OF SMALL DROPLET)=    0
XDDIN(INITIAL WATER CONTENT OF LARGE DROPLET)= .040
RHUMID(INITIAL RELATIVE HUMIDITY)=   .00 PER CENT
XCH4(INITIAL METHANE CONTENT)=    0

TOG(COMPRESSOR INLET TOTAL TEMPRATURE OF GAS)= 518.70
TOW(COMPRESSOR INLET TEMPERATURE OF DROPLRET)= 513.70
PO(COMPRESSOR INLET TOTAL PRESSURE)=   2116.80

DIN(INITIIL DROPLET DIAMETER OF SMALL DROPLET)=  20.0
DDIN(INITIAL DROPLET DIAMETER OF LARGE DROPLET)= 600.0

FND(DESIGN ROTATIONAL SPEED)=51120.0

DSMASS(DESIGN MASS FLOW RATE)=     .3755

COMPRESSOR INLET TATAL TEMPERATURE(GAS PHASE) 518.70

COMPRESSOR INLET TOTAL PRESSURE=   2116.80

PREB(PERCENT OF WATER THAT REBOUND AFTER IMPINGE   MENT)= 50.0 PERCENT

ROTOR SPEED=51120.0 RPM

CORRECTED ROTOR SPEED= 51120.0 RPM(  100.0PER CENT OF DESIGN CORRECTED SPEED)
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*************** DESIGN POINT INFORMATION *********** ***

***** COMPRESSOR INLET *****

TOTAL TEMPERATURE AT COMPRESSOR INLET= 518.70000
TOTAL PRESSURE AT COMPRESSOR INLET=   2116.80
STATIC TEMPERATURE AT COMPRESSOR INLET= 496.28109
STATIC PRESSURE AT COMPRESSOR INLET=   1813.73
STATIC DENSITY AT COMPRESSOR INLET=    .06850

ACOUSTIC SPEED AT COMPRESSOR INLET=1092.25914
AXIAL VELOCITY AT COMPRESSOR INLET= 518.81873
MACH NUMBER AT COMPRESSOR INLET=    .47500
STREAMTUBE AREA AT COMPRESSOR INLET=    .01057
FLOW COEFFICIENT AT COMPRESSOR INLET=    .53817
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*************** DESIGN POINT INFORMATION ************ ***

***** STAGE= 1 *****

	TOTAL TEMP	TOTAL PRESSURE	STATIC TEMP	STATIC PRESSURE	STATIC DENSITY
ROTOR INLET	518.700	2116.800	492.637	1767.579	.067
ROTOR OUTLET	541.148	2442.787	508.269	1961.576	.072

	AXIAL VELOCITY	ABSOLUTE VELOCITY	RELATIVE VELOCITY	TAN COMP OF ABS VEL	TAN COMP OF REL VEL
ROTOR INLET	538.76531	559.39838	725.32398	150.52734	485.62003
ROTOR OUTLET	525.97105	628.55682	618.75550	344.14838	325.90306

	ROTOR SPEED	ABS MACH NUMBER	REL MACH NUMBER	REL TOTAL TEMP	REL TOTAL PRESSURE
ROTOR INLET	636.147	.514	.667	536.454	2381.210
ROTOR OUTLET	670.051	.569	.560	540.141	5091.790

	ABS FLOW ANGLE	REL FLOW ANGLE	STREAMTUBE AREA	RADIUS	FLOW COEFFICIENT
ROTOR INLET	15.61000	42.03015	.01036	1.42600	.55886
ROTOR OUTLET	33.19714	31.78325	.00987	1.50200	.54559

STAGE TOTAL PRESSURE RATIO AT DESIGN POINT= 1.15200
STAGE ADIABATIC EFFICIENCY AT DESIGN POINT= .95383
ROTOR TOTAL PRESSURE RATIO AT DESIGN POINT= 1.15400
ROTOR ADIABATIC EFFICIENCY AT DESIGN POINT= .96600
ROTOR TOTAL TEMPERATURE RATIO AT DESIGN POINT= 1.04328

*************** DESIGN POINT INFORMATION ************ ***

***** STAGE= 2 *****

	TOTAL TEMP	TOTAL PRESSURE	STATIC TEMP	STATIC PRESSURE	STATIC DENSITY
ROTOR INLET	541.148	2438.554	511.984	2008.852	.074
ROTOR OUTLET	566.141	2840.915	522.316	2142.394	.077

	AXIAL VELOCITY	ABSOLUTE VELOCITY	RELATIVE VELOCITY	TAN COMP OF ABS VEL	TAN COMP OF REL VEL
ROTOR INLET	549.21299	591.88727	730.68951	220.67086	481.94632
ROTOR OUTLET	581.16447	725.94045	639.44211	435.01464	266.71034

	ROTOR SPEED	ABS MACH NUMBER	REL MACH NUMBER	REL TOTAL TEMP	REL TOTAL PRESSURE
ROTOR INLET	702.617	.534	.659	556.431	2688.136
ROTOR OUTLET	701.725	.648	.571	556.331	5751.007

	ABS FLOW ANGLE	REL FLOW ANGLE	STREAMTUBE AREA	RADIUS	FLOW COEFFICIENT
ROTOR INLET	21.89000	41.26765	.00930	1.57500	.56970
ROTOR OUTLET	36.81569	24.65154	.00841	1.57300	.60285

STAGE TOTAL PRESSURE RATIO AT DESIGN POINT= 1.15900
STAGE ADIABATIC EFFICIENCY AT DESIGN POINT= .93231
ROTOR TOTAL PRESSURE RATIO AT DESIGN POINT= 1.16500
ROTOR ADIABATIC EFFICIENCY AT DESIGN POINT= .96600
ROTOR TOTAL TEMPERATURE RATIO AT DESIGN POINT= 1.04618

*************** DESIGN POINT INFORMATION ************ ***

***** STAGE= 3 *****

	TOTAL TEMP	TOTAL PRESSURE	STATIC TEMP	STATIC PRESSURE	STATIC DENSITY
ROTOR INLET	566.141	2826.284	535.362	2323.868	.081
ROTOR OUTLET	600.462	3450.892	549.786	2533.049	.086

	AXIAL VELOCITY	ABSOLUTE VELOCITY	RELATIVE VELOCITY	TAN COMP OF ABS VEL	TAN COMP OF REL VEL
ROTOR INLET	574.81563	608.26663	784.29006	198.93541	533.57089
ROTOR OUTLET	614.43880	781.11343	662.59507	482.28950	247.98627

	ROTOR SPEED	ABS MACH NUMBER	REL MACH NUMBER	REL TOTAL TEMP	REL TOTAL PRESSURE
ROTOR INLET	732.506	.536	.692	586.533	3199.070
ROTOR OUTLET	730.276	.680	.577	586.263	6929.751

	ABS FLOW ANGLE	REL FLOW ANGLE	STREAMTUBE AREA	RADIUS	FLOW COEFFICIENT
ROTOR INLET	19.09000	42.86892	.00803	1.64200	.59626
ROTOR OUTLET	38.12932	21.97890	.00708	1.63700	.63736

STAGE TOTAL PRESSURE RATIO AT DESIGN POINT= 1.21300
STAGE ADIABATIC EFFICIENCY AT DESIGN POINT= .93464
ROTOR TOTAL PRESSURE RATIO AT DESIGN POINT= 1.22100
ROTOR ADIABATIC EFFICIENCY AT DESIGN POINT= .96800
ROTOR TOTAL TEMPERATURE RATIO AT DESIGN POINT= 1.06062

*************** DESIGN POINT INFORMATION ************ ***

***** STAGE= 4 *****

	TOTAL TEMP	TOTAL PRESSURE	STATIC TEMP	STATIC PRESSURE	STATIC DENSITY
ROTOR INLET	600.462	3428.282	569.069	2839.988	.094
ROTOR OUTLET	639.381	4240.785	585.841	3118.959	.100

	AXIAL VELOCITY	ABSOLUTE VELOCITY	RELATIVE VELOCITY	TAN COMP OF ABS VEL	TAN COMP OF REL VEL
ROTOR INLET	580.04590	614.69778	809.54747	203.47020	564.72459
ROTOR OUTLET	619.63965	803.61317	668.93304	511.70446	252.02926

	ROTOR SPEED	ABS MACH NUMBER	REL MACH NUMBER	REL TOTAL TEMP	REL TOTAL PRESSURE
ROTOR INLET	768.195	.526	.692	623.519	3912.431
ROTOR OUTLET	763.734	.678	.564	622.951	8231.914

	ABS FLOW ANGLE	REL FLOW ANGLE	STREAMTUBE AREA	RADIUS	FLOW COEFFICIENT
ROTOR INLET	19.33000	44.23321	.00692	1.72200	.60169
ROTOR OUTLET	39.55025	22.13332	.00607	1.71200	.64276

STAGE TOTAL PRESSURE RATIO AT DESIGN POINT= 1.22800
STAGE ADIABATIC EFFICIENCY AT DESIGN POINT= .93002
ROTOR TOTAL PRESSURE RATIO AT DESIGN POINT= 1.23700
ROTOR ADIABATIC EFFICIENCY AT DESIGN POINT= .96500
ROTOR TOTAL TEMPERATURE RATIO AT DESIGN POINT= 1.06481

*************** DESIGN POINT INFORMATION ************ ***

***** STAGE= 5 *****

	TOTAL TEMP	TOTAL PRESSURE	STATIC TEMP	STATIC PRESSURE	STATIC DENSITY
ROTOR INLET	639.381	4209.930	606.962	3506.755	.108
ROTOR OUTLET	679.732	5178.214	625.197	3857.244	.116

	AXIAL VELOCITY	ABSOLUTE VELOCITY	RELATIVE VELOCITY	TAN COMP OF ABS VEL	TAN COMP OF REL VEL
ROTOR INLET	586.84149	625.22167	826.78513	215.68308	582.40082
ROTOR OUTLET	617.08868	811.98444	669.65381	527.75042	260.07304

	ROTOR SPEED	ABS MACH NUMBER	REL MACH NUMBER	REL TOTAL TEMP	REL TOTAL PRESSURE
ROTOR INLET	798.084	.518	.685	663.653	4798.526
ROTOR OUTLET	787.823	.663	.547	662.302	9691.778

	ABS FLOW ANGLE	REL FLOW ANGLE	STREAMTUBE AREA	RADIUS	FLOW COEFFICIENT
ROTOR INLET	20.18000	44.78240	.00591	1.78900	.60873
ROTOR OUTLET	40.53794	22.85308	.00526	1.76600	.64011

STAGE TOTAL PRESSURE RATIO AT DESIGN POINT= 1.22100
STAGE ADIABATIC EFFICIENCY AT DESIGN POINT= .92580
ROTOR TOTAL PRESSURE RATIO AT DESIGN POINT= 1.23000
ROTOR ADIABATIC EFFICIENCY AT DESIGN POINT= .96200
ROTOR TOTAL TEMPERATURE RATIO AT DESIGN POINT= 1.06311

############### DESIGN POINT INFORMATION ############ ###

STAGE= 6

	TOTAL TEMP	TOTAL PRESSURE	STATIC TEMP	STATIC PRESSURE	STATIC DENSITY
ROTOR INLET	679.732	5140.325	646.933	4318.954	.125
ROTOR OUTLET	720.259	6245.495	665.989	4736.291	.133

	AXIAL VELOCITY	ABSOLUTE VELOCITY	RELATIVE VELOCITY	TAN COMP OF ABS VEL	TAN COMP OF REL VEL
ROTOR INLET	587.19574	629.60666	833.74045	227.16890	591.88199
ROTOR OUTLET	603.39773	811.09676	654.61329	542.02320	253.83017

	ROTOR SPEED	ABS MACH NUMBER	REL MACH NUMBER	REL TOTAL TEMP	REL TOTAL PRESSURE
ROTOR INLET	819.051	.506	.669	704.449	5829.034
ROTOR OUTLET	795.853	.642	.518	701.350	10970.182

	ABS FLOW ANGLE	REL FLOW ANGLE	STREAMTUBE AREA	RADIUS	FLOW COEFFICIENT
ROTOR INLET	21.15000	45.22772	.00511	1.83600	.60910
ROTOR OUTLET	41.93288	22.81494	.00467	1.78400	.62591

STAGE TOTAL PRESSURE RATIO AT DESIGN POINT= 1.20800
STAGE ADIABATIC EFFICIENCY AT DESIGN POINT= .92365
ROTOR TOTAL PRESSURE RATIO AT DESIGN POINT= 1.21500
ROTOR ADIABATIC EFFICIENCY AT DESIGN POINT= .95400
ROTOR TOTAL TEMPERATURE RATIO AT DESIGN POINT= 1.05962

*************** DESIGN POINT INFORMATION ************ ***

********** OVERALL PERFORMANCE AT DESIGN POINT **** ******

COMPRESSOR INLET TOTAL TEMPERATURE= 518.70

COMPRESSOR INLET TOTAL PRESSURE= 2116.80

CORRECTED MASS FLOW RATE= 3.168

OVERALL TOTAL PRESSURE RATIO=2.9334

OVERALL TOTAL TEMPERATURE RATIO=1.3886

OVERALL ADIABATIC EFFICIENCY= .9223

OVERALL TEMPERATURE RISE= 201.559

	1	2	3	4	5	6	IGV
BET1SR(I)	42.03	41.27	42.97	44.23	44.78	45.23	
BET2SR(I)	31.78	24.65	21.98	22.13	22.85	22.81	
AINCSR(I)	-.69	-1.47	1.25	1.38	.78	.16	
ADEVSR(I)	5.99	7.48	8.86	8.37	8.52	8.38	
BET1SS(I)	33.20	36.82	38.13	39.55	40.54	41.93	
BET2SS(I)	21.89	19.09	19.33	20.18	21.15	34.86	15.61
AINCSS(I)	-1.95	-3.29	-5.23	-5.45	-5.77	-6.78	
ADEVSS(I)	9.70	7.96	8.82	8.37	7.83	5.58	
TD(I)	518.7	541.1	566.1	600.5	639.4	679.7	
OMEGS(I)	.009	.021	.025	.028	.029	.024	
OMEGR(I)	.020	.021	.024	.028	.030	.036	

******************** INITIAL FLOW COEFFICIENT- .50000 (STAGE= 1) ********************

STAGE TOTAL PRESSURE RATIO= 1.16790
STAGE TOTAL TEMPERATURE RATIO= 1.05044
STAGE ADIABATIC EFFICIENCY= .89932

STAGE FLOW COEFFICIENT= .500
AXIAL VELOCITY= 482.10
ROTOR SPEED= 964.04

STAGE TOTAL PRESSURE RATIO(ACTUAL)= 1.16790
STAGE TOTAL PRESSURE RATIO(IDEAL)= 1.18781
LOSS FACTOR IN ROTOR= 1.01167
LOSS FACTOR IN STATOR= .99536

	ROTOR INLET	*ROTOR OUTLET*	*STATOR OUTLET*
TOTAL PRESSURE	2116.80	2483.73	2472.21
STATIC PRESSURE	1822.02	2027.51	2105.98
TOTAL TEMPERATURE(GAS)	518.7000	544.8657	544.8657
STATIC TEMPERATURE(GAS)	496.9285	515.3151	521.3902
STATIC DENSITY(GAS)	.0687	.0737	.0757
STATIC DENSITY(MIXTURE)	.0716	.0768	.0789
AXIAL VELOCITY	482.0985	471.7651	487.8474
ABSOLUTE VELOCITY	500.9664	595.7508	530.9922
RELATIVE VELOCITY	694.5315	562.4474	
BLADE SPEED	636.1474	670.0514	702.6172
TANG. COMP. OF ABS. VEL.	136.1924	363.8085	
TANG. COMP. OF REL. VEL.	499.9550	306.2429	
ACOUSTIC SPEED	1070.9380	1090.5707	1096.9841
ABSOLUTE MACH NUMBER	.4678	.5463	.4840
RELATIVE MACH NUMBER	.6485	.5157	
FLOW COEFFICIENT	.5001	.4894	.5060
FLOW AREA	.0104	.0099	.0093
ABSOLUTE FLOW ANGLE	15.7749	37.6381	23.2615
RELATIVE FLOW ANGLE	46.0417	32.9893	
INCIDENCE	3.3217	2.4881	
DEVIATION		7.1993	11.0715

******************** INITIAL FLOW COEFFICIENT= .50000 (ISTAGE= 1) ****************

STAGE PERFORMANCE AFTER INTER-STAGE ADJUSTMENT(JPERFM=3)

STAGE TOTAL PRESSURE RATIO= 1.16790
STAGE TOTAL TEMPERATURE RATIO= 1.05044
STAGE ADIABATIC EFFICIENCY= .89932

	STAGE INLET	**STAGE OUTLET** (BEFORE INTER-STAGE ADJUSTMENT)	**STAGE OUTLET** (AFTER INTER-STAGE ADJUSTMENT)
XV=	.00000	.00000	.00000
XW=	0	0	.01801
XWW=	.04000	.04000	.02199
XWT=	.04000	.04000	.04000
XAIR=	.96000	.96000	.96000
XMETAN=	0	0	0
XGAS	.96000	.96000	.96000
WMASS=	0	0	.00644
WWMASS=	.01431	.01431	.00786
WTMASS=	.01431	.01431	.01431
AMASS=	.34340	.34340	.34340
CHMASS=	0	0	0
VMASS=	.00000	.00000	.00000
GMASS=	.34340	.34340	.34340
TMASS=	.35771	.35771	.35771
WS=	.00000	.00000	.00000
RHOA=	.07649	.07395	.06767
RHOM=	.07160	.07702	.07902
RHOG=	.06872	.07395	.07586
TG=	518.70000	544.86572	544.86571
TW=	513.70000	513.70000	513.70000
TWW=	513.70000	513.70000	513.70012
P=	2116.80000	2483.73050	2472.21005
TB=	671.40656	0	679.08227
TDEW=	271.99506	273.28391	339.24784

****************** INITIAL FLOW COEFFICIENT- .50000 (STAGE= 2) ******************

STAGE TOTAL PRESSURE RATIO= 1.16781
STAGE TOTAL TEMPERATURE RATIO= 1.05175
STAGE ADIABATIC EFFICIENCY= .87555

STAGE FLOW COEFFICIENT= .505
AXIAL VELOCITY= 486.86
ROTOR SPEED= 964.04

STAGE TOTAL PRESSURE RATIO(ACTUAL)= 1.16781
STAGE TOTAL PRESSURE RATIO(IDEAL)= 1.19311
LOSS FACTOR IN ROTOR= .98822
LOSS FACTOR IN STATOR= .98982

	ROTOR INLET	*ROTOR OUTLET*	*STATOR OUTLET*
TOTAL PRESSURE	2472.21	2916.76	2887.07
STATIC PRESSURE	2106.74	2255.26	2462.37
TOTAL TEMPERATURE(GAS)	544.8657	573.0631	573.0631
STATIC TEMPERATURE(GAS)	520.5178	533.9732	548.5689
STATIC DENSITY(GAS)	.0759	.0792	.0841
STATIC DENSITY(MIXTURE)	.0790	.0825	.0876
AXIAL VELOCITY	486.8556	516.0982	508.2930
ABSOLUTE VELOCITY	529.9329	685.3880	542.5448
RELATIVE VELOCITY	693.1121	573.7782	
BLADE SPEED	702.6172	701.7250	732.5063
TANG. COMP. OF ABS. VEL.	209.2856	450.9981	
TANG. COMP. OF REL. VEL.	493.3315	250.7269	
ACOUSTIC SPEED	1095.9433	1110.0181	1125.0890
ABSOLUTE MACH NUMBER	.4835	.6175	.4822
RELATIVE MACH NUMBER	.6324	.5169	
FLOW COEFFICIENT	.5050	.5354	.5273
FLOW AREA	.0093	.0084	.0080
ABSOLUTE FLOW ANGLE	23.2615	41.1489	20.4692
RELATIVE FLOW ANGLE	45.3785	25.9111	
INCIDENCE	2.6385	1.0389	
DEVIATION		8.7411	9.3392

******************** INITIAL FLOW COEFFICIENT= .50000 (ISTAGE= 2) ****************

STAGE PERFORMANCE AFTER INTER-STAGE ADJUSTMENT(JPERFM=3)

STAGE TOTAL PRESSURE RATIO= 1.16781
STAGE TOTAL TEMPERATURE RATIO= 1.05175
STAGE ADIABATIC EFFICIENCY= .87561

	STAGE INLET	**STAGE OUTLET** (BEFORE INTER-STAGE ADJUSTMENT)	**STAGE OUTLET** (AFTER INTER-STAGE ADJUSTMENT)
XV=	.00000	.00000	.00012
XW=	.01801	.01801	.02726
XWW=	.02199	.02199	.01262
XWT=	.04000	.04000	.03988
XAIR=	.96000	.96000	.96000
XMETAN=	0	0	0
XGAS	.96000	.96000	.96012
WMASS=	.00644	.00644	.00975
WWMASS=	.00786	.00786	.00452
WTMASS=	.01431	.01431	.01427
AMASS=	.34340	.34340	.34340
CHMASS=	0	0	0
VMASS=	.00000	.00000	.00004
GMASS=	.34340	.34340	.34344
TMASS=	.35771	.35771	.35771
WS=	.00000	.00000	.00012
RHOA=	.08504	.07945	.07525
RHOM=	.07160	.08276	.08779
RHOG=	.07586	.07945	.08429
TG=	544.86571	573.06306	573.06071
TW=	513.70000	519.14631	519.16899
TWW=	513.70012	513.70012	513.70036
P=	2472.21005	2916.76359	2887.07247
TB=	679.08227	0	686.93158
TDEW=	339.24784	341.32476	419.65418

******************** INITIAL FLOW COEFFICIENT- .50000 (STAGE= 3) ********************

STAGE TOTAL PRESSURE RATIO= 1.21691
STAGE TOTAL TEMPERATURE RATIO= 1.06493
STAGE ADIABATIC EFFICIENCY= .88732

STAGE FLOW COEFFICIENT= .526
AXIAL VELOCITY= 507.38
ROTOR SPEED= 964.04

STAGE TOTAL PRESSURE RATIO(ACTUAL)= 1.21691
STAGE TOTAL PRESSURE RATIO(IDEAL)= 1.24647
LOSS FACTOR IN ROTOR= .98667
LOSS FACTOR IN STATOR= .98789

	ROTOR INLET	*ROTOR OUTLET*	*STATOR OUTLET*
TOTAL PRESSURE	2887.07	3556.35	3513.29
STATIC PRESSURE	2463.17	2688.47	3014.69
TOTAL TEMPERATURE(GAS)	573.0607	610.2670	610.2670
STATIC TEMPERATURE(GAS)	547.6584	565.1550	585.1747
STATIC DENSITY(GAS)	.0843	.0892	.0966
STATIC DENSITY(MIXTURE)	.0878	.0929	.1006
AXIAL VELOCITY	507.3826	544.2751	513.9069
ABSOLUTE VELOCITY	541.5777	736.6414	549.3895
RELATIVE VELOCITY	743.2430	592.3993	
BLADE SPEED	732.5063	730.2758	768.1948
TANG. COMP. OF ABS. VEL.	189.3921	496.3922	
TANG. COMP. OF REL. VEL.	543.1142	233.8835	
ACOUSTIC SPEED	1124.0705	1141.8852	1161.9377
ABSOLUTE MACH NUMBER	.4818	.6451	.4728
RELATIVE MACH NUMBER	.6612	.5188	
FLOW COEFFICIENT	.5263	.5646	.5331
FLOW AREA	.0080	.0071	.0069
ABSOLUTE FLOW ANGLE	20.4692	42.3656	20.7047
RELATIVE FLOW ANGLE	46.9481	23.2540	
INCIDENCE	5.3281	-.9944	
DEVIATION		10.1340	10.1947

******************** INITIAL FLOW COEFFICIENT= .50000 (ISTAGE= 3) ****************

STAGE PERFORMANCE AFTER INTER-STAGE ADJUSTMENT(JPERFM=3)

STAGE TOTAL PRESSURE RATIO= 1.21691
STAGE TOTAL TEMPERATURE RATIO= 1.06490
STAGE ADIABATIC EFFICIENCY= .88760

	STAGE INLET	**STAGE OUTLET** (BEFORE INTER-STAGE ADJUST-MENT)	**STAGE OUTLET** (AFTER INTER-STAGE ADJUST-MENT)
XV=	.00012	.00012	.00077
XW=	.02726	.02726	.03181
XWW=	.01262	.01262	.00743
XWT=	.03988	.03988	.03923
XAIR=	.96000	.96000	.96000
XMETAN=	0	0	0
XGAS	.96012	.96012	.96077
WMASS=	.00975	.00975	.01138
WWMASS=	.00452	.00452	.00266
WTMASS=	.01427	.01427	.01403
AMASS=	.34340	.34340	.34340
CHMASS=	0	0	0
VMASS=	.00004	.00004	.00027
GMASS=	.34344	.34344	.34367
TMASS=	.35771	.35771	.35771
WS=	.00012	.00012	.00080
RHOA=	.09443	.08952	.08667
RHOM=	.07160	.09323	.10063
RHOG=	.08429	.08951	.09668
TG=	573.06071	610.26699	610.25190
TW=	519.16899	526.02007	526.13187
TWW=	513.70036	513.70036	513.70075
P=	2887.07247	3556.34709	3513.29461
TB=	686.93158	0	697.12854
TDEW=	419.65418	423.67496	463.62629

******************** INITIAL FLOW COEFFICIENT= .50000 (STAGE= 4) ******************

STAGE TOTAL PRESSURE RATIO= 1.23667
STAGE TOTAL TEMPERATURE RATIO= 1.06871
STAGE ADIABATIC EFFICIENCY= .90751

STAGE FLOW COEFFICIENT= .533
AXIAL VELOCITY= 513.61
ROTOR SPEED= 964.04

STAGE TOTAL PRESSURE RATIO(ACTUAL)= 1.23667
STAGE TOTAL PRESSURE RATIO(IDEAL)= 1.26254
LOSS FACTOR IN ROTOR= .98671
LOSS FACTOR IN STATOR= .98960

	ROTOR INLET	*ROTOR OUTLET*	*STATOR OUTLET*
TOTAL PRESSURE	3513.29	4390.45	4344.80
STATIC PRESSURE	3014.95	3322.28	3749.71
TOTAL TEMPERATURE(GAS)	610.2519	652.1841	652.1841
STATIC TEMPERATURE(GAS)	584.2131	604.1817	626.3816
STATIC DENSITY(GAS)	.0967	.1030	.1121
STATIC DENSITY(MIXTURE)	.1006	.1072	.1167
AXIAL VELOCITY	513.6087	549.3247	518.6059
ABSOLUTE VELOCITY	549.0705	760.6511	557.6792
RELATIVE VELOCITY	770.2922	598.5017	
BLADE SPEED	768.1948	763.7337	798.0839
TANG. COMP. OF ABS. VEL.	194.1249	526.1487	
TANG. COMP. OF REL. VEL.	574.0699	237.5850	
ACOUSTIC SPEED	1161.2398	1202.4310	1202.4238
ABSOLUTE MACH NUMBER	.4728	.6441	.4638
RELATIVE MACH NUMBER	.6633	.5068	
FLOW COEFFICIENT	.5328	.5698	.5380
FLOW AREA	.0069	.0061	.0059
ABSOLUTE FLOW ANGLE	20.7047	43.7655	21.5751
RELATIVE FLOW ANGLE	48.1816	23.3887	
INCIDENCE	5.3316	-1.2345	
DEVIATION		9.6287	9.7651

******************** INITIAL FLOW COEFFICIENT= .50000 (ISTAGE= 4) ****************

STAGE PERFORMANCE AFTER INTER-STAGE ADJUSTMENT(JPERFM=2)

STAGE TOTAL PRESSURE RATIO= 1.23667
STAGE TOTAL TEMPERATURE RATIO= 1.06864
STAGE ADIABATIC EFFICIENCY= .90822

	STAGE INLET	**STAGE OUTLET** (BEFORE INTER-STAGE ADJUSTMENT)	**STAGE OUTLET** (AFTER INTER-STAGE ADJUSTMENT)
XV=	.00077	.00077	.00248
XW=	.03181	.03181	.03307
XWW=	.00743	.00743	.00445
XWT=	.03923	.03923	.03752
XAIR=	.96000	.96000	.96000
XMETAN=	0	0	0
XGAS	.96077	.96077	.96248
WMASS=	.01138	.01138	.01183
WWMASS=	.00266	.00266	.00159
WTMASS=	.01403	.01403	.01342
AMASS=	.34340	.34340	.34340
CHMASS=	0	0	0
VMASS=	.00027	.00027	.00089
GMASS=	.34367	.34367	.34429
TMASS=	.35771	.35771	.35771
WS=	.00080	.00080	.00259
RHOA=	.10791	.10346	.10094
RHOM=	.07160	.10763	.11655
RHOG=	.09668	.10341	.11218
TG=	610.25190	652.18409	652.14134
TW=	526.13187	533.30984	533.59527
TWW=	513.70075	513.70036	513.70137
P=	3513.29461	4390.44609	4344.79698
TB=	697.12854	0	708.50906
TDEW=	463.62629	468.88156	498.37453

******************** INITIAL FLOW COEFFICIENT= .50000 (STAGE= 5) ******************

STAGE TOTAL PRESSURE RATIO= 1.22899
STAGE TOTAL TEMPERATURE RATIO= 1.06675
STAGE ADIABATIC EFFICIENCY= .90336

STAGE FLOW COEFFICIENT= .539
AXIAL VELOCITY= 519.37
ROTOR SPEED= 964.04

STAGE TOTAL PRESSURE RATIO(ACTUAL)= 1.22899
STAGE TOTAL PRESSURE RATIO(IDEAL)= 1.25515
LOSS FACTOR IN ROTOR= .98250
LOSS FACTOR IN STATOR= .98967

	ROTOR INLET	*ROTOR OUTLET*	*STATOR OUTLET*
TOTAL PRESSURE	4344.80	5395.45	5339.72
STATIC PRESSURE	3748.75	4131.68	4643.21
TOTAL TEMPERATURE(GAS)	652.1413	695.6709	695.6709
STATIC TEMPERATURE(GAS)	625.3469	646.6178	669.5503
STATIC DENSITY(GAS)	.1122	.1196	.1298
STATIC DENSITY(MIXTURE)	.1165	.1242	.1348
AXIAL VELOCITY	519.3675	547.1502	519.0957
ABSOLUTE VELOCITY	558.4980	770.3315	562.1291
RELATIVE VELOCITY	788.0677	599.7321	
BLADE SPEED	798.0839	787.8235	819.0509
TANG. COMP. OF ABS. VEL.	205.3714	542.2521	
TANG. COMP. OF REL. VEL.	592.7125	245.5713	
ACOUSTIC SPEED	1202.5460	1243.7812	1244.3279
ABSOLUTE MACH NUMBER	.4644	.6300	.4518
RELATIVE MACH NUMBER	.6553	.4904	
FLOW COEFFICIENT	.5387	.5676	.5385
FLOW AREA	.0059	.0053	.0051
ABSOLUTE FLOW ANGLE	21.5751	44.7424	22.5764
RELATIVE FLOW ANGLE	48.7734	24.1714	
INCIDENCE	4.7734	-1.5676	
DEVIATION		9.8414	9.2564

******************** INITIAL FLOW COEFFICIENT= .50000 (ISTAGE= 5) ****************

STAGE PERFORMANCE AFTER INTER-STAGE ADJUSTMENT(JPERFM=2)

STAGE TOTAL PRESSURE RATIO= 1.22899
STAGE TOTAL TEMPERATURE RATIO= 1.06664
STAGE ADIABATIC EFFICIENCY= .90448

	STAGE INLET	**STAGE OUTLET** (BEFORE INTER-STAGE ADJUSTMENT)	**STAGE OUTLET** (AFTER INTER-STAGE ADJUSTMENT)
XV=	.00248	.00248	.00559
XW=	.03307	.03307	.03080
XWW=	.00445	.00445	0
XWT=	.03752	.03752	.03080
XAIR=	.96000	.96000	.96360
XMETAN=	0	0	0
XGAS	.96248	.96248	.96920
WMASS=	.01183	.01183	.01098
WWMASS=	.00159	.00159	0
WTMASS=	.01342	.01342	.01098
AMASS=	.34340	.34340	.34340
CHMASS=	0	0	0
VMASS=	.00089	.00089	.00199
GMASS=	.34429	.34429	.34539
TMASS=	.35771	.35771	.35637
WS=	.00259	.00259	.00580
RHOA=	.12487	.12017	.11734
RHOM=	.07160	.12465	.13382
RHOG=	.11218	.11998	.12971
TG=	652.14134	695.67091	695.59860
TW=	533.59527	540.88803	541.37489
TWW=	513.70137	513.70036	513.70155
P=	4344.79698	5395.45042	5339.72029
TB=	708.50906	0	722.80827
TDEW=	498.37453	496.93587	520.46557

******************** INITIAL FLOW COEFFICIENT= .50000 (STAGE= 6) ******************

STAGE TOTAL PRESSURE RATIO= 1.21378
STAGE TOTAL TEMPERATURE RATIO= 1.06246
STAGE ADIABATIC EFFICIENCY= .90205

STAGE FLOW COEFFICIENT= .540
AXIAL VELOCITY= 521.03
ROTOR SPEED= 964.04

STAGE TOTAL PRESSURE RATIO(ACTUAL)= 1.21378
STAGE TOTAL PRESSURE RATIO(IDEAL)= 1.23841
LOSS FACTOR IN ROTOR= .97381
LOSS FACTOR IN STATOR= .99141

	ROTOR INLET	*ROTOR OUTLET*	*STATOR OUTLET*
TOTAL PRESSURE	5339.72	6537.40	6481.27
STATIC PRESSURE	4643.05	5093.62	5499.02
TOTAL TEMPERATURE(GAS)	695.5986	739.0448	739.0448
STATIC TEMPERATURE(GAS)	668.5834	690.0533	706.4154
STATIC DENSITY(GAS)	.1297	.1379	.1454
STATIC DENSITY(MIXTURE)	.1338	.1422	.1500
AXIAL VELOCITY	521.0291	536.5871	508.8163
ABSOLUTE VELOCITY	564.2700	771.9356	629.9781
RELATIVE VELOCITY	796.4797	588.1877	
BLADE SPEED	819.0509	795.8534	.5000
TANG. COMP. OF ABS. VEL.	216.6319	554.9404	
TANG. COMP. OF REL. VEL.	602.4190	240.9130	
ACOUSTIC SPEED	1248.0901	1282.9307	1282.9214
ABSOLUTE MACH NUMBER	.4521	.6088	.4910
RELATIVE MACH NUMBER	.6382	.4639	
FLOW COEFFICIENT	.5405	.5566	.5307
FLOW AREA	.0051	.0047	.0047
ABSOLUTE FLOW ANGLE	22.5764	45.9633	36.1308
RELATIVE FLOW ANGLE	49.1436	24.1788	
INCIDENCE	4.0736	-2.7467	
DEVIATION		9.7488	6.8508

******************** INITIAL FLOW COEFFICIENT= .50000 (ISTAGE= 6) ****************

STAGE PERFORMANCE AFTER INTER-STAGE ADJUSTMENT(JPERFM=2)

STAGE TOTAL PRESSURE RATIO= 1.21378
STAGE TOTAL TEMPERATURE RATIO= 1.06219
STAGE ADIABATIC EFFICIENCY= .90445

	STAGE INLET	**STAGE OUTLET** (BEFORE INTER-STAGE ADJUSTMENT)	**STAGE OUTLET** (AFTER INTER-STAGE ADJUSTMENT)
XV=	.00559	.00559	.01742
XW=	.03080	.03080	.01898
XWW=	0	0	0
XWT=	.03080	.03080	.01898
XAIR=	.96360	.96360	.96360
XMETAN=	0	0	0
XGAS	.96920	.96920	.98102
WMASS=	.01098	.01098	.00676
WWMASS=	0	0	0
WTMASS=	.01098	.01098	.00676
AMASS=	.34340	.34340	.34340
CHMASS=	0	0	0
VMASS=	.00199	.00199	.00621
GMASS=	.34539	.34539	.34961
TMASS=	.35637	.35637	.35637
WS=	.00580	.00580	.01807
RHOA=	.14388	.13869	.12770
RHOM=	.07160	.14259	.14690
RHOG=	.12971	.13821	.14412
TG=	695.59860	739.04479	738.85892
TW=	541.37489	548.44179	549.82046
TWW=	513.70155	513.70036	513.70155
P=	5339.72029	6537.39986	6481.26579
TB=	722.80827	0	734.62173
TDEW=	520.46557	526.83752	564.70213

********** OVERALL PERFORMANCE *********

INITIAL FLOW COEFFICIENT= .50000

CORRECTED SPEED=51120.0   1.000 FRACTION OF DEIGN CORRECTED SPEED

INITIAL WATER CONTENT(SMALL DROPLET)=   0
INITIAL WATER CONTENT(LARGE DROPLET)= .040
INITIAL WATER CONTENT(TOTAL)= .040
INITIAL RELATIVE HUMIDITY=   .0 PER CENT
INITIAL METHANE CONTENT=   0

COMPRESSOR INLET TOTAL TEMPERATURE= 518.70

COMPRESSOR INLET TOTAL PRESSURE=   2116.80

CORRECTED MASS FLOW RATE OF MIXTURE= .358(3.018)

CORRECTED MASS FLOW RATE OF GAS PHASE   .343(2.897)

OVERALL TOTAL PRESSURE RATIO=3.0618

OVERALL TOTAL TEMPERATURE RATIO=1.4244

OVERALL ADIABATIC EFFICIENCY= .8805

OVERALL TEMPERATURE RISE OF GAS PHASE= 220.159

LIST OF REFERENCES

1. Willenborg, J.A., et al., "F-111 Engine Water Ingestion Review," F-111 System Program Office, Wright-Patterson Air Force Base, Dayton, Ohio, October 31-November 10, 1972.
2. Useller, J.W., et al., "Effect of Heavy Rainfall on Turbojet Aircraft Operation," Aeronautical Engineering Review, February, 1955.
3. MacGregor, C.A. and Bremer, R.J., "An Analytical Investigation of Water Ingestion in the B-1 Inlet," Rockwell International, NA-73-181, June 1973.
4. (a) "Concorde Complete Flooded Runway Tests," Aviation Week and Space Technology, p.22, October 4, 1971.
   (b) "Board Assays Crash of DC-9 in Storm," Ibid, pp. 63-67, July 24, 1978.
   (c) "Storm Traced in Southern DC-9 Crash," Ibid, pp. 59-61, July 31, 1978.
   (d) "Damage Assessed in Southern Crash," Ibid, pp. 59-63, August 7, 1978.
   (e) "Thrust Loss Cited in Southern Accident," Ibid, pp 55-58, August 21, 1978.
   (f) "Board Urges Improved Thunderstorm Reporting," Ibid, pp. 63-64 August 28, 1978.

(5) Papadaes, B.S. and Taylor, D.W., "A Review of Sea Loiter Aircraft Technology," AIAA Paper No. 76-876, September , 1976.

(6) Pfeifer, G.D. and Maier, G.P., "Engineering Summary of Powerplant Icing Technical Data," Federal Aviation Administration Report No. FAA-RD-77-76, July, 1977.

(7) Danielson, K. and Huggins, A.W., "Raindrop Size Distribution Measurement of High Elevation Continental Cumuli," Conference on Cloud Physics, pp. 305-310, October 1974.

(8) Fowler, M.G., et al., "Cloud Droplet Measurements in Cumuliform and Stratiform Clouds," Ibid, pp 296-299, October 1974

(9) Kissel, G.J., "Rain and Hail Extremes at Altitude," AIAA Paper No. 79-0539, February , 1979.

(10) Hearsey, R.M., "A Revised Computer Program for Axial Compressor Design," Wright-Patterson Air Force Base Aerospace Research Laboratories, ARL TR 75-0001, Volume I and II.

(11) (a) Murthy, S.N.B., et al., "Water Ingestion Into Axial Flow Compressors" Report No. AFAPL-TR-76-77, Air Force Systems Command, Wright-Patterson Air Force Base, August, 1976.

(b) Murthy, S.N.B., et al., "Analysis of Water Ingestion Effects in Axial Flow Compressors," Report No. AFAPL-TR-78-35, Air Force Systems Command, Wright-Patterson Air Force Base, June, 1978.

(12) Grant, G. and Tabakoff, W., "Erosion Prediction in Turbomachinery Resulting from Environmental Solid Particles,: Jr. of Aircraft, Volume 12, No.5, pp 471-478, May, 1975.

13. Tabakoff, W. et al., "Effect of Solid Particles on Turbine Performance," Transaction of the ASME, Jr. of Engineering for Power, pp. 47-52, January, 1976

(14) Marble, F.E., "Nozzle Contours for Minimum Particle-Lag Loss," AIAA Journal, Volume 1, No. 12, pp. 2793-2801, December, 1963.

(15) Korkan, K.D., et al., "Particle Concentrations in High Mach Number Two-Phase Flows, " AIAA Paper No. 74-606, July 1974.

(16) Hoffman, J.D., "An Analysis of the Effects of Gas-Particle Mixtures on the Performance of Rocket Nozzles," Ph.D. Thesis, Purdue University, January, 1963.

(17) Moore, M.J., and Sieverding, C.H., Two Phase Steam Flow in Turbines and Separators, McGraw-Hill, New York, 1976.

(18) Gardner, G.O., "Events Leading to Turbine Blade Erosion," Proc. Inst. Mech. Eng., Vol. 178, Pt. 1 No. 23, pp. 593-624, 1964.

(19) Keller, H., Erosionskorrosion on Heissdampfturbinen VGB Kraftwekstechnik, 1974, Heft 5.

(20) Diagnostics and Engine Condition Monitoring, AGARD-CP-165, June 1975.

(21) "Distortion Induced Engine Instability," Advisory Group for Aerospace Research and Development, Lecture Series, AGARD-LS-72, December, 1974.

(22) Tsuchiya,T. and Murthy, S.N.B., "Water Ingestion into Axial Flow Compressors." Part I, Analysis and Predictions, Technical Report AFWAL-TR-80-2090, October 1980.

(23) Lieblein,S., "Loss and Stall Analysis of Compressor Cascades," Jr. of Basic Engineering, Transaction of the ASME, September, 1959.

(24) Swan, W.C., "A Practical Method of Predicting Transonic-Compressor Performance," Jr. of Engineering, Transaction of the ASME, July 1961.

(25) Soo, S.L., "Boundary Layer Motion of a Gas-Solids Suspension," Proceedings of Interaction Between Fluids and Particles, pp. 50-63, Instn. Chem Engrs., London, October, 1961.

(26) Schlichting, H., Boundary-Layer Theory, McGraw-Hill Book Co., Inc. New York, 1955.

(27) Collier, J.G. and Wallis, G.B., Two-Phase Flow and Heat Transfer, Vol II, pp. 405, Dep. of Mechanical Engineering, Stanford University, Palo Alto, California, 1967.

(28) Holman, J.P., Heat Transfer, p. 427, McGraw-Hill, New York, 1976.

(29) Zucrow, M.J. and Hoffman, J.D., Gas Dynamics, Vol. I, pp. 55-57 John Wiley & Sons, New York, 1976.

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